WORKS BY THE SAME AUTHOR.

[*Geographical Series.*

MACMILLAN AND CO., Ltd., LONDON.

Science Primers

GEOLOGY

BY

SIR ARCHIBALD GEIKIE

F.R.S.; D.C.L.; D.Sc.; LL.D.

Director-General of the Geological Survey of the United Kingdom
and formerly ison Professor of Geology and
Mineralog the University of Edinburgh

WITH ILLUSTRATIONS

904253

London
MACMILLAN AND CO., LIMITED
NEW YORK: THE MACMILLAN COMPANY
1902

All rights reserved

First Edition printed 1873.
Reprinted 1874, 1875, 1876, 1877, 1878, 1880, 1881.
Second Edition 1884. *Reprinted* 1886, 1888, 1891, 1893, 1898.
Third Edition 1900, 1902.

PREFACE

THE following Lessons having been designed to be based on practical instruction, teachers and learners will find it of great advantage to obtain and use a small collection of specimens. In a favourable locality the teacher may make his own collection; otherwise he will do well to procure one of those described on pages 159-60, and accustom his pupils from the very beginning to familiarise their eyes with the specimens described in the Lessons.

From the sale of successive large impressions of this little book in this country and America, as well as in translations on the Continent, I am led to hope that its practical method has been found of service in education. I have been urged to introduce into these Lessons some account of the Geological Formations and other details usually to be found in elementary class-books. But my definite aim in the conception and execution of the book was to present only as much detail as was needful to illustrate methods of observation and principles of deduction which seemed capable of being taught in an interesting way to young boys and girls. My desire is merely to stimulate curiosity and induce inquiry. If these are aroused, the learner will have no difficulty in finding sources of further information, and my object will be fully attained. For the use of more advanced pupils I have prepared a Class-Book of Geology.

The present edition of this Primer has been thoroughly revised.

April 1900.

CONTENTS

ART. PAGE
INTRODUCTORY . . . . . . 1—14 1
STONES OR ROCKS—THEIR VARIOUS KINDS 15—33 8
WHAT STONES HAVE TO TELL US . . 34—41 18

SEDIMENTARY ROCKS :—

I. What Sediment is . . . . 42—54 24
II. How Gravel, Sand, and Mud are made . . . . . . 55—69 29
III. How Gravel, Sand, and Mud become Sedimentary Rocks . . 70—93 39
IV. How the Remains of Plants and Animals come to be found in Sedimentary Rocks . . . 94—103 53
V. A Quarry and its Lessons . . 104—116 59

ORGANICALLY-DERIVED ROCKS, OR ROCKS FORMED OF THE REMAINS OF PLANTS AND ANIMALS :—

I. Rocks formed of the Remains of Plants . . . . . . 117—137 66
II. Rocks formed of the Remains of Animals . . . . . . 138—147 78

IGNEOUS ROCKS :—

	ART.	PAGE
I. What Igneous Rocks are . .	148—161	86
II. Where Igneous Rocks come from .	162—172	98

THE CRUST OF THE EARTH :—

I. Proofs that parts of the Crust have been pushed up . . .	173—192	106
II. Proofs that parts of the Crust have sunk down	193—203	118
III. Proofs that the Rocks of the Earth's Crust have been tilted, crumpled, and broken	204—212	124
IV. The Origin of Mountains . .	213—228	130
V. How the Rocks of the Crust tell the History of the Earth . . .	229—240	140
CONCLUSION	241—246	148

SCIENCE PRIMERS

GEOLOGY

INTRODUCTORY

1. An ordinary dwelling-house, such as those in which most of us live, is built of various materials, of which one is always **stone.** The walls, the hearths, the chimney-pieces, and the roofs, are commonly of stone, different kinds being used for each of these parts of the building. Thus the walls may be made of freestone, limestone, or brick, the hearths of flagstone, the roofs of slate or tiles, the chimney-pieces of marble, while yet another sort of stone called coal is burnt in the fireplaces. In the streets a still greater variety may be seen. The causeway stones are of one sort, those of the foot-pavement of another. Many different ornamental kinds are made use of in the shops and buildings. So that merely by looking at houses and streets we may readily perceive that **there are many different kinds of stone.**

2. Further examination will show that the stones thus employed receive various treatment before they become part of a building. Those of the walls have been chipped and dressed with chisels and hammers; the marble of the chimney-pieces has been cut and polished; the slates have been split into thin plates. Some have undergone still greater changes. The bricks, for instance, were originally soft clay, which has been hardened by being baked in ovens. The mortar that holds the stones or bricks of the walls together has been obtained by burning limestone in kilns. The iron used in the house was first of all in the state of a dull red or brown stone, which had to be roasted and melted before the clear bright metal came out of it. And so, too, with the copper, brass, tin, and other metals, out of which so many articles of domestic use are made.

3. But although stones differ in so many ways from each other, they agree in one point—**they come from underneath the surface of the ground.** Hence, as they are dug out or mined, they are known by the general name of **mineral** substances. If we could trace back each of them to the place whence it came, we should find the freestone and limestone to have been taken out of quarries, perhaps not very far away, the slates to have been cut out of the side of some hill, the marble to have been quarried out of some distant mountain, the coal to have been brought up out of mines, sunk deep into the earth, and the bricks to have been made from

clay dug out of pits on some low ground, not improbably in the neighbourhood.

4. In the long-settled parts of the Old and New World, such, for instance, as the British Isles, the greater part of the surface has a green grassy covering, even over the sides of the hills. Cornfields, meadows, orchards, woods and forests spread over it, concealing what lies beneath them, as a carpet hides a floor. But this mantle of vegetation, with the soil on which it grows, is only a thin coating. One can easily dig through it, or, better still one can watch its removal in quarries, pits, railway-cuttings or excavations of any kind. The vegetation and its underlying soil form a mere outer layer, only a few feet thick at the most. Underneath them there always lies some kind of stone. So that just as in pulling up the carpet of a room we lay bare a wooden floor, so in peeling off the outer skin of vegetation and soil from any part of the land we expose a stone floor.

5. On this floor of stone we are walking every day of our lives. It stretches all over the globe, forming the bottom of the sea and the surface of the land. Unlike the floors of our houses, it is very uneven, spreading out in some places into wide flat plains, and shooting up elsewhere into high, rugged mountains.

6. Again, this vast world-wide floor differs from our little wooden floors in the wonderful variety of its materials. We see only a small part of this variety in the various stones employed in building.

There is an almost endless number of other stones which are not in use. A builder is content if he can get his floors made of one uniform sort of wood that will last. But the great stone floor on which we are living has no such uniformity. Its varied materials are grouped together in the most irregular and changing manner, insomuch that a map of them all, as they are distributed over a country, somewhat resembles the intricate pattern of an Eastern carpet.

7. It is to the study of this stone floor that the following Lessons are to be devoted—what it is made of, and how its different parts were put together. At first sight, perhaps, there may seem to be nothing very interesting or attractive in such a subject. The following illustration may serve to show how much the character and history of a people, and the aspects of our everyday life are influenced by the varying nature and shape of the stone floor on which we live.

8. Take a map of the British Islands and draw across it two pencilled lines. Let one of these lines begin at Liverpool and stretch across England, touching Stafford, Birmingham, and Cambridge, to the sea at Harwich. Let the other run across the breadth of Scotland from the island of Skye to Montrose.[1]

9. Suppose that two foreigners, who had never been in the country, were to land on the west coast,

---

[1] A similar illustration has been used by Buckland, in his Bridgewater Treatise.

and after crossing the island, each along one of the lines you have drawn, were afterwards to meet again on the Continent and compare notes as to what they had seen. The traveller who journeyed along the line from Liverpool to Harwich might report in some such words as these:—"I am astonished at the flatness of Britain. I went across the whole breadth of the island and did not see a single undulation of the ground worthy of the name of a hill. Most of the land is wonderfully fertile, being in one part covered with corn-fields, in another with orchards or woods, while wide tracts are given up to pasture. The houses are built of brick. I saw some large cities crowded with people and alive with all kinds of industry. I noticed, too, that in some parts of the country a great deal of the wealth of the inhabitants comes from underground. In Cheshire they obtain large quantities of salt by pumping up brine from mines and borings sunk below ground. In Staffordshire they extract coal and iron from numerous deep pits. But, on the whole, Britain seems to me given up to the growing of crops and the feeding of cattle, while a large part of the population is gathered into towns and cities for purposes of manufacture."

10. The other traveller would have a very different story to tell. "I cannot understand," he might say, "how you can talk of Britain as in any sense a flat country. I too crossed the island from sea to sea, landing on the coast of Inverness-shire

and sailing from the port of Montrose. But I could see very little low or level land the whole way. It is an endless succession of rough high mountains and deep rocky valleys. I could see no towns, hardly any villages, until I came to the eastern coast. The people live in houses of stone; I could not see a single brick anywhere. They have no coals except what are brought from a distance, and most of the poorer people cut the peat on the moors and use it for fuel. I saw no mines in my journey, and no manufactures of any kind. The population is but scanty, and seems to be occupied chiefly with sheep-farming and rearing cattle. Large regions are almost uninhabited and are given up to game. If I might judge of the whole of Britain from what I have seen with my own eyes, I would describe it as a rough, mountainous, barren island, without commerce or industry, and fit only for pasture-land or grouse-shooting, and here and there, in the valleys, for tillage."

11. Now each of these supposed travellers would have given a true enough account of the country, so far as his own personal experience of it went. And yet both of them would have been quite wrong in supposing that what he had seen to be true of one part of the country was equally true of the whole.

12. In almost every country of Europe and America, and in short all over the globe, similar contrasts may be observed. Now, why is it that there should be this great difference between different

portions of the same country? What makes one region mountainous, another level; one fertile, another barren; one crowded with people and the scene of all manner of industry, another thinly peopled and given up to the breeding of sheep and the shooting of game?

13. **These great differences in the scenery of a country and the character of its inhabitants depend upon differences in the stones or rocks.** If then the aspect of a country and the habits and pursuits of the people are so much influenced by the nature of the stones underneath, it is very desirable to know something about these stones,—what they consist of, how they have been put together, and why it is that they should form plains or low grounds in one place, and single hills or chains of mountains in another.

14. A little consideration of the subject reveals to us that different kinds of stones have had their own special history, which when learnt reveals some curious and interesting glimpses into former conditions of land and sea. By degrees we observe that the history of the earth itself may, in great measure, be deciphered from these stones. The science which treats of these questions is called **Geology**, or that branch of human inquiry which is devoted to the history of the earth.

STONES OR ROCKS—THEIR VARIOUS KINDS.

15. One of the first objects to be aimed at in making some acquaintance with Geology, is to have a clear notion of the main points in which stones resemble and differ from each other. They are the materials for compiling the story of the earth. If we are to follow this story intelligently, therefore, and still more, if we are to try to interpret any part of it for ourselves, we must arrange our materials so as to understand precisely how they are to be used, and what kind of information we may expect to gain from them. One of the great advantages of Geology is that it lies open to everybody. The questions with which it deals are suggested by many of the familiar objects of everyday life, and any intelligent inquirer may hope not only to understand these questions, but to be able to add something new to the knowledge already acquired by others regarding them.

16. To any one who has travelled a little, or even to one who, not having travelled, has seen a collection of mineral products in the cases of a museum, it may seem as if the number and variety of stones were so great and confusing, as to make the task of trying to study them difficult and irksome. And in one sense this impression is not without justification. Nevertheless, it is possible,

greatly to reduce the difficulty and wearisomeness of the pursuit. Let me illustrate this matter in the following way :—

17. Suppose the question were put to us, to state how many different kinds of books we had met with in our lifetime. We should hardly be able to make any very satisfactory answer without some consideration. Our first impression would no doubt be that it would be nearly impossible to count up all the various sorts of books; and we might find it difficult to decide which books should be regarded as belonging to the same kinds, and which to different kinds. Some agree with each other in being new, others in being old; some are of one size, some are of another; some are covered with boards, others merely wrapped up in paper; some bound in cloth, others cased in leather and covered with rich gilding; some printed in English, others in French, German, Italian, Latin, or Greek. But in reflecting on these and similar differences we see that they all are concerned with the mere outside, or external, non-essential parts of the books. It is not the paper, or printing, or binding, or age, nor even the language, that is the important part of a book, but the thoughts which the book has to make known to us. These thoughts might be printed in a large book or a small one, in English, French, German, or any other language, but they would remain the same thoughts, and the book would be essentially the same book all the while.

18. When we pass, then, from the mere unimportant external resemblances or differences to what the books properly are in themselves, we soon discover that, after all, there are not so many kinds as at first might have been supposed. We can pick them out and sort them into groups, according to the subjects of which they treat. Thus, taking as examples only such as are used by young readers, we find that some are Books of Grammar, others Books of History, others Books of Geography, with Books of Poetry, Books of Travels, Books of Tales, and so on. Under each of these names we could put, if we had them, hundreds of books, resembling each other in treating about the same things, though outwardly they might be utterly unlike each other, as to size, binding, age, and even language.

19. In arranging our books in this way, not according to their mere superficial, accidental resemblances, but according to the subjects which they treat of in common, that is, their real resemblances, we would follow what is called a **Principle of Classification.** It would not matter how many different books came into our hands, nor in how many different languages they might be written, still, following our principle of classification, we should be able to arrange them all in their proper places, books on the same subject being always put together, so that at any moment we could lay hands on any particular book that might be wanted.

20. Suppose that instead of books we try to

arrange stones according to their several kinds. We first think over the names of all the different stones we can remember, and try to recollect their characters. Perhaps we begin by arranging them according to colour—Black Stones, such as Coal; White Stones, such as Chalk, and so on. But in a little time we find that the same stone, marble, for instance, is sometimes black and sometimes white. Plainly, therefore, colour will not do for our principle of classification. Then we might attempt a grouping into Hard Stones and Soft Stones. But we soon discover that we need to put side by side stones so utterly unlike each other that we feel sure that mere hardness or softness must be an accidental or outside character, like the paper or printing of a book.

21. We must determine what are the real and essential characters of stones. In dealing with books with a view to their proper classification we examined their contents, and placed those together which we found to be devoted to the same subject. Obviously the same kind of treatment must be followed in any proper arrangement of stones.

22. How then are we to learn what are the essential characters of stones? At first this may seem a hopelessly difficult task. But though there are undoubtedly difficulties, many of them disappear as we look more closely at them. We soon perceive that a simple principle of classification may be found, and that by its help stones may be arranged into a very

much smaller number of groups than could have been anticipated. Let us try this practically by some examples.

23. Here are three pieces of stone :—

1. A piece of Sandstone.
2. A piece of Granite.
3. A piece of Chalk, or Limestone.

These stones are of such common occurrence that they are probably familiar to most readers of this book. Those who do not know them by sight can easily procure pieces of them, and ought to do so, if they would intelligently follow these lessons. Sandstone is abundantly used for walls, lintels, hearths, and flagstones. Granite may now be frequently seen in polished columns and slabs in public buildings, shops, and in tombstones; while the streets in many of our large cities and towns are now paved with it. Common white chalk needs no description; but in districts where it cannot be procured a piece of limestone containing "fossils" (see Art. 94) will serve the same purpose.

24. Take the piece of sandstone in your hands and examine it carefully, using even a magnifying glass if the grains are minute. Then write down each of the characters that are observed, one after another. You will, of course, pay little heed to colour, for sandstones may be red, white, green, yellow, or indeed of almost any colour. Nor will you give much weight to hardness or softness as an essential character, for you may find, even in the

same piece of stone, that one part is quite hard, while a neighbouring place is soft and crumbling.

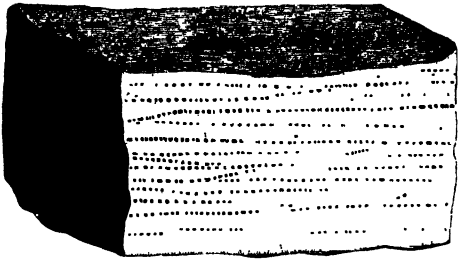

FIG. 1.—Piece of Sandstone.

25. If the piece of sandstone has been well chosen, you will be able to write down the following characters :—

(1.) The stone is made up of small grains.

(2.) The grains are more or less rounded or worn.

(3.) By scraping the surface of the stone these rounded grains can be separated from the stone, and when they lie in this loose state they are seen to be mere grains of sand.

(4.) More careful examination of the stone may show that the grains tend to lie in planes, which run in a general way parallel with each other, and that it is along the surfaces of these planes that the stone most easily breaks or splits.

(5.) The grains differ from each other in size and in the material of which they are made. Most of them, though they may look dull, white, yellow, red, or green on the outside, yet when broken across are found to consist of a very hard, clear, nearly or quite colourless substance like glass; some are perhaps small spangles of a material that glistens like silver; others are softer, and look like a kind of dull earth of the same general colour as the stone. The various distinct grains lie touching each other in some sandstones; in others they are separated by a kind of cement that binds them all into a solid stone. It is this cement which usually colours a sandstone, since it is often red or yellow, and sometimes green, brown, purple, or even black.

26. Summing up these characters in a short definition, we may describe our specimen of sandstone as **a stone composed of worn, rounded grains of various other stones or mineral substances arranged in layers.**

27. Proceeding in the same way with the piece of Granite, you find at once a very different set of appearances, but after a little time you will be able to make out and to write down the following:—

(1.) The stone contains no rounded grains.

(2.) It is composed of three different substances or minerals, each of which has a peculiar crystalline form (see Chemistry Primer, Art. 23). Thus, one of these, called Felspar, lies in long smooth-faced, more or less sharply-defined crystals, or crystalline patches, of a pale flesh colour, or dull white, which can with some difficulty be scratched with the point of a knife. These are the long white sharp-edged objects shown in the drawing (Fig. 2). Another, termed Mica, lies in bright, glistening silvery plates, which can easily be scratched, and split up into thin transparent leaves. If these shining plates are compared with the little silvery spangles in the sandstone, they will be seen to be the same material. The third, named Quartz, is a very hard, clear, glassy substance, on which the knife makes no impression, but which may be recognised as the same material out of which most of the grains of the sandstone are made.

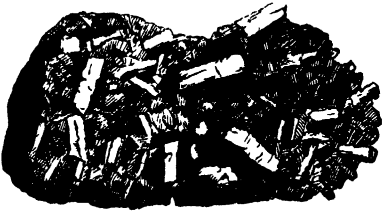

FIG 2.—Piece of Granite.

(3.) The crystals in granite do not occur in any definite order, but are scattered at random through the whole of the stone, and seem to be implanted in each other.

28. Here are characters strikingly different from those of the sandstone. They may be grouped into some such short definition as this — Granite is a **stone composed of several distinct crystalline minerals, which have no definite arrangement, but are irregularly interlaced with each other.**

29. Applying the same process of examination to

the piece of Chalk, you may be inclined at first to declare that this stone has no distinct characters at all. It is a soft, white, crumbling substance, soils the fingers when touched, and seems neither to have grains like the sandstone nor crystals like the granite. A magnifying glass, or even perhaps a microscope, may be needed to show the real nature of the stone. Take a fine brush and rub off a little powder from the chalk into a glass of clear water; then shake the water gently and let it stand for a while until you see a layer of sediment on the bottom. Pour off the water, place a little of the sediment upon a piece of glass, and look at it under a magnifying glass or microscope. (See Art. 142.) It will be observed to present strongly-marked characters, which may be set down thus:—

(1.) The stone, though much finer grained and more uniform in texture than either sandstone or granite, is made up of minute particles resembling each other in colour and composition, but presenting a variety of individual forms.

(2.) It consists of various minute shells, recognisable fragments of larger shells and sea-urchins, pieces of coral, fragments of sponges, and white particles which are evidently the broken-down remains of different "organisms," that is, once-living creatures. In Fig. 3 some of these chalk grains are represented as they appear when placed under a microscope which magnifies them fifty times. Larger and well-preserved shells, sea-urchins, and remains of other sea-creatures occur imbedded in chalk. (See Fig. 23.)

30. These characters might be summed up into the following brief but, so far as it goes, correct definition of Chalk—**a stone formed out of the remains of once-living animals.**

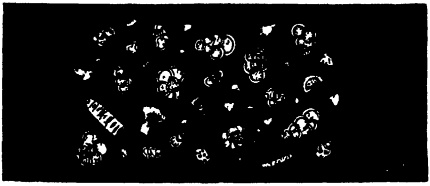

Fig 3 —Some of the Grains of a piece of Chalk

31. If a piece of Chalk cannot be had, it may be possible to procure a fragment of limestone composed mainly or entirely of recognisable fragments of shells, or other "organic remains." Such a specimen might be a firmly-compacted stone, and of almost any colour. It might be as unlike chalk as chalk is unlike granite, and yet if it consisted of the cemented fragments of once-living animals, it would obviously come under the same definition as that given in the previous paragraph (see Fig. 24, p. 83).

32. This kind of practical examination should be repeated again and again, until the characters which have been written down here have become quite familiar to you. These three stones are, in fact, examples of three great groups into which most of the rocks of the world may be arranged. So that

when the composition of a piece of sandstone, or chalk, or granite is thoroughly and practically mastered, a foundation of knowledge and observation is laid which will serve as an excellent starting-point for geological study, and which will pave the way for the comprehension of how the stones of the mountains, valleys, and sea-shores came into existence.

33. In spite, then, of the apparently infinite diversity of the stones of which the globe is built up, they may, by a little study, be grouped into few classes. Following a simple principle of classification, we find that each stone we may meet with falls naturally into its own proper group. Without laying too much stress on the mere outer shape and hue, we endeavour to discover what are the fundamental points on which a stone differs from others, and what are its essential characters. We seek to learn of what it is made, and what is its structure; and according to the result of our inquiries we place it in the Sandstone group, or the Granite group, or the Chalk group.

WHAT STONES HAVE TO TELL US.

34. But if we went no farther than merely to be able to arrange stones under their proper divisions, it would be hardly worth while to study them at all. We should be like people who had put a library into such excellent order that every volume stood on its proper shelf and compartment, ready for easy

reference at any moment, but who, after all, rested content with this mere systematic arrangement, never opening any of the books to make themselves acquainted with the contents as well as with the titles. The classification of stones, or of flowers, birds, fishes, or any other objects in nature, is in itself of no more service than such an arranging of a library, unless it is turned to account in helping us to understand better the nature of the things we classify, and how they are related to each other.

35. This habit of classifying what we discover lies at the base of all true science. Without it we could make but little progress; we should always be in a maze, and would never know what to make of each new thing we might find out. We should be somewhat like people turned into a great hall and required to educate themselves there, with the floors and galleries strewn all over with piles of books in all languages and on every subject, but utterly and hopelessly in confusion.

36. Let us now try how this habit can be established among the seemingly endless variety of stones with which the world is stored, and how it will help us to make progress in our inquiries there. We take again our pieces of sandstone, chalk, and granite, and compare other stones with them. We repair to the nearest pit, quarry, or ravine, to any opening in fact, either natural or artificial, which will enable us to see down beneath the grass and the soil of the surface. In one place there may be a clay-pit,

in another a sandstone-quarry, in another a railway cutting through solid rock, in another a deep ravine with picturesque rocky sides and a stream flowing at the bottom. It does not matter for our present purpose what the nature of the opening be, provided it shows what lies beneath the soil. In all such places stone or rock of some kind, or of many different kinds, will be met with. The word "rock" is used in geology to denote any naturally-formed mass of mineral matter, whether it be hard or soft, compact or loose. Hence, blown sand, mud, clay, gravel, and peat are, in the geological sense, "rocks" quite as much as granite, sandstone, or limestone. After a little practice, the observer learns that the various sorts of rocks may usually be arranged under one or other of the three divisions already mentioned. For example, a large number of stones will be found to agree with the general definition of Sandstone (Arts. 24-26). These will of course be placed together in the Sandstone group. Another considerable quantity of stones will be met with, made up wholly or almost wholly of the remains of plants or of animals. These must evidently be arranged in the Chalk group. Lastly, a good many stones are built up of interlocked crystals of different kinds. There are many different kinds of crystals, but, without troubling ourselves in the meantime with these differences, we may, provisionally at least, class crystalline rocks in the Granite group.

37. In this way, we should advance from the mere

pieces of stone that can be held in the hand, up to the masses of rock lying under a whole parish, or a county, or even the entire country. If the investigation were made in England, for example, it would gradually teach us that a long range of hills, stretching completely across the island from the coasts of Dorsetshire to those of Yorkshire, is formed of chalk, and that other parts of the country lie upon rocks in many respects resembling chalk. It would show us that a great part of Britain is made of stone like our piece of sandstone; for example, the hills and dales of most of Wales, Lancashire, and the South of Scotland. And if we climbed up to the tops of the mountains, such as the higher summits of the Grampians, of Wales, or of Ireland, we should find them to be built up of solid masses of granite, or of rocks that would come into our Granite group. A little observation, in any part of the world, is enough to enable us easily to gather satisfactory evidence that the different kinds of stone are not scattered at random over the ground, but have each their own places, with their own forms of hill or valley.

38. Further attention to these matters will ere long convince us that, if we only learn how to question rocks in the right way, we may get from them tolerably clear and definite answers. In fact they may be compared to books, each of which contains a little piece of history. And much in the same way as we must know the language in which a book has been written, if we would understand what the book has

to tell us, so, if we would comprehend the history recorded in the rocks, we should begin by trying to master the methods by which the record is to be interpreted. Of these methods the following pages are intended to give some account. The history told by the rocks is that of the land we live in, how it has been made, and what wonderful changes it has seen. In reading historical books we follow the events that happened in old times in a country, how battles were fought, laws were made, and old habits and customs gradually passed away. As the more we know about the events of former times, the better do we understand how the laws and customs of the present day came to be what they are, so, on the other hand, the more we can make ourselves familiar with the processes of Nature that are changing the surface of the globe at the present time, the better fitted are we to trace out the chronicles of the olden time of our planet's history as recorded in the rocks.

39. The solid earth under our feet has likewise a history, as well as the people who have lived on its surface. Take Britain as an example. By the study of its rocks, men have found out that once a great part of this country, as well as of Northern Europe and North America, was buried under ice, like Greenland. Earlier still, it was the scene of vast volcanic eruptions that deluged thousands of square miles with streams of molten rock. Beyond that time, it had jungles of palms and other tropical plants: yet farther back, it lay beneath a wide sea

that stretched across the whole of what is now the centre of Europe; and beyond that time can be traced many still more remote periods, when it was forest-covered land or wide marshy plains, or again buried under the sea. And amid these mutations of the face of nature, the plants and the animals, alike of the land and the sea, have slowly undergone a long series of changes. As we trace their remains backward into the older rocks in which they lie entombed, they become more and more unlike the plants and animals of to-day. Thus, basing our inquiries on the actual evidence furnished by the rocks, we may follow step by step this strange history backwards, with almost as much certainty as we trace the progress of the Romans over the ancient world, or of the Angles, Saxons, and Jutes in England.

40. The records of these old revolutions of the earth's surface are contained in the stones beneath our feet. In learning what these stones are, how they were made, and how they came to be as we now see them, we are really unravelling a part of the history of the earth. This history is written in clear and legible language, which, with a little patience, will easily be mastered. And when the ability to read it has once been acquired, we shall not be content with what we can learn from books. When we discover that the commonest bit of stone has its part of the story to tell, which we can read from it for ourselves, we obtain a constant and increasing source of delight in getting away to quarries, brooks, sea-shores,

or hill-sides, to any place, in short, where the rocks can be examined, that we may question them and learn what they have to tell about the ancient chronicles of the earth.

41. The object of this little book is to set its readers in the way of putting intelligent questions to every stone and rock they may meet with. We will begin with the very simplest lessons, and, appealing at every step to things already familiar, will feel, in this way, how sure and steady our progress is, till, in the end, it will be practicable to carry on the questioning with little help from book or friend. The same changes that are now in progress on the surface of the land and on the floor of the sea have been advancing from remote periods of the past, producing the same kind of effects. In proportion, therefore, as we appreciate and observe the order of nature at the present time, are we fitted to understand and follow out the records of similar events in the earlier history of the earth—records that are duly chronicled among the rocks which it is the business of Geology to investigate.

SEDIMENTARY ROCKS.

I. What Sediment is.

42. The stones or rocks beneath our feet, therefore, are full of a history of old revolutions of the earth. To be able to read this history, we obviously require at least two qualifications. We must know

how to observe, and then how to arrange and compare our observations. The mode of observing was illustrated in the foregoing pages by the way in which definitions were found for different kinds of stone. The habit of arrangement was exemplified in the classification of three groups of rock.

43. We called these for convenience the Sandstone group, the Chalk group, and the Granite group. But other names for them are already in use, which will be more convenient. Accordingly we will refer all rocks having characters like those of sandstone to the **Sedimentary Rocks**; those formed, as chalk is, of the remains of plants or animals, to the **Organically-formed Rocks**; and those having a crystalline character, like our granite group, to the **Igneous Rocks.** The meaning of these names will be seen as we proceed.

44. Now, since these groups are so distinct from each other, it may reasonably be inferred, even at the outset, and before anything more is known about them, that each of them has a history peculiar to itself; in other words, that its various kinds of rock must have been formed differently from those of the other groups, since they are so unlike them. Let us, then, take up each of the groups in succession, beginning with the Sedimentary Rocks, or those which have a more or less close resemblance to sandstone.

45. But first, we must clearly understand the meaning of this word **sedimentary**, and why it is

applied to the rocks of this group. We take a glass of water and put some clean well-washed gravel into it. The gravel at once sinks to the bottom, and remains there even though the water be briskly stirred. We close the mouth of the glass and shake it up and down, so as to mix the water and gravel thoroughly together; but as soon as this is done and the glass is placed on the table again, the gravel is found to have sunk and formed a layer at the bottom as before. This layer of coarse mineral particles deposited in water is a **sediment of gravel.**

46. Instead of gravel, we put clean sand into the water and shake it up as before. We mix them so completely that for a moment or two after we cease, the water seems quite dirty. But in a few minutes, or in a longer time, if the particles happen to be very fine, the sand will have all sunk to the bottom as a layer below the water. This layer is a **sediment of sand.**

47. We next take a little mud or clay, and shake it up in the water until the two are thoroughly mixed. When the glass is replaced on the table this time, the water continues quite dirty. Even after some hours it remains still discoloured. But a layer which soon began to settle down at the bottom continues to increase in thickness, and if the glass is allowed to stand long enough undisturbed, this layer will continue growing until the water has again become clear. In this case the layer is a **sediment of mud.**

48. Sediment, therefore, is something which, after

having been suspended in, or moved along by, water, has settled down upon the bottom. The coarser and heavier the sediment the quicker will it sink; while, when very fine, it may remain in suspension in the water for a long time.

49. Sedimentary Rocks are consequently those which have been formed out of sediments. And just as sediments differ from each other in coarseness or fineness, so must the sedimentary rocks formed out of them.

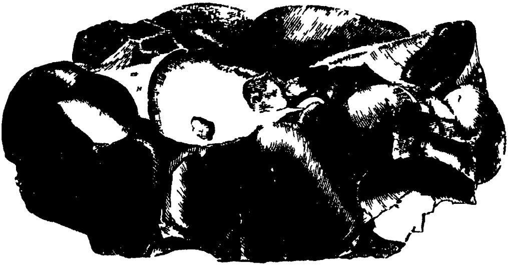

FIG 4 Piece of Conglomerate or Pudding-stone.

50. Here are pieces of three sedimentary rocks:—

(1.) A piece of **Conglomerate** or pudding-stone (Fig. 4).

(2.) The piece of **Sandstone** examined already (Fig. 1); and

(3.) A piece of **Shale** (Fig. 5).

51. The first of these three specimens is found on examination to be made of little rounded stones, cemented together. Were these round stones to be

separated from each other, and gathered into a loose heap, we would at once call it a heap of gravel. The stone is evidently nothing more than so much hardened gravel, such as might be picked up on the sea-shore, by the side of a lake, or in the channel of a stream. Such a rock is sometimes called pudding-stone, because the stones lie together in it, somewhat like the fruit in a plum-pudding.

52. Taking up the piece of sandstone again, and making a further examination of it, let us consider if we have ever seen anything like the grains of which it is made up. Obviously they are grains of sand, and the sandstone therefore consists of mere sand firmly compacted into a stone. On the sea-shore, or on the bed of a brook or river, sand of very much the same kind may be found, which, if it were hardened into a compact mass, would make just such a sandstone.

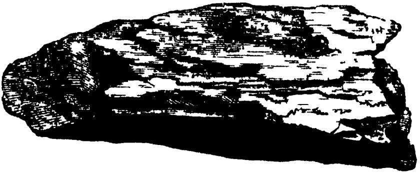

FIG. 5.— Piece of Shale

53. In the third specimen the grains of the stone are not so easily seen, being small. But take a knife and scrape the end of the stone, working up the powder with some drops of water. Put now the

dull-brown or black paste which is thus made into a tumbler of water and stir it well round. Immediately the water becomes dirty, and remains so even for some time afterwards. But put the tumbler aside for some hours and you will find that the water clears again; that what was put in as a dirty paste has sunk to the bottom of the glass as a layer of sediment, and that it is simply mud. The shale, therefore, is nothing more than a stone formed of hardened, fine muddy sediment, just as the conglomerate is formed out of compacted coarse gravelly sediment, and the sandstone of compacted sandy sediment.

54. Thus the term Sedimentary Rocks is an expressive one. It includes rocks formed of all kinds of sediment whether coarse or fine.

In examining rocks belonging to this division two questions must be considered. First of all, how was the sediment made out of which they have been formed? and secondly, how did the sediment come to be gathered and hardened into solid stone?

II. How Gravel, Sand, and Mud are made.

55. The first step in the study of the Sedimentary Rocks has been taken in the foregoing Lesson, where it was shown that they consist of sediment, such as gravel, sand, and mud. The next step must be to find out how those materials have been formed, and how they have been gathered together into the con-

dition of compact rocks. At the outset of all such inquiries in geology, the question should be asked: Is there anything going on nowadays that will explain what we are in search of? By starting fresh from the observation of what takes place at the present time, we are far better able to understand what has been done long ago. How then are gravel, sand, and mud made at the present day?

56. The difference between gravel and sand will be found, after a little examination, to be only in the size of their component materials. In gravel the stones are large, in sand they are mere grains. To make this clear, place a little sand under a strong magnifying glass. The grains will look perhaps like gravel-stones rather than particles of sand. Each grain is found to be a worn, rounded stone, sometimes with little chips and hollows on its sides, like those on the sides of pebbles which we may pick out of a heap of gravel. After examining the sand in this way, we become convinced that, in spite of their contrast in size of grain, sand and gravel are only different states of the same thing. Indeed, it is quite easy to collect a series of samples showing every gradation from fine sand to coarse gravel. By the side of a rapid stream, or on a rocky coast, for example, we may pass in a few yards from fine sand or silt up to the largest shingle, with huge rounded blocks many tons in weight. In such a scene we can hardly help asking how all these fragments, whether small or large, come to be broken off, ground so

round and smooth, and heaped up where we now see them.

57. To find a satisfactory answer to this question, let us suppose ourselves to be far up among the hills, at the first beginning of the brooks. Where the rocks are hard and tough, they rise out of the hill-sides as prominent crags and cliffs, down which little streamlets dance from ledge to ledge, before they unite into larger streams in the bottoms of the valleys. The crags are full of rifts; tall masses of them seem ready to topple down, and the slopes below are strewn with blocks of all sizes that have already fallen. Rocks exposed to the weather, in a country where there is plenty of rain, and where the winters are cold, suffer great waste. They are split up by rain and frost. How this work is done is explained in the Physical Geography Primer, Arts. 133-147. We have now to consider some of the results of the waste.

58. Suppose, for the sake of distinctness, that one special crag could be singled out, the rock of which, from its colour or composition, might be distinguished, even in small fragments, from those of the crags round about it. Rising boldly from a steep hill-side, it looks perhaps down a long slope to the little stream, which in the distance seems a thread of silver winding through the green meadows far below. In the long course of time, rain and frost have carved the front of this crag into deep clefts and gullies, which, when wet weather sets in, become each the channel of a torrent, that pours down the slope and sweeps

away every loose bit of stone or earth within its reach.

59. Were we to climb along the face of the crag and look into some of these frost-splintered, torrent-swept gullies, we should find them a scene of utter ruin. The bottom of each of them would be seen choked up with blocks of all sizes that have tumbled down from the cliffs on either hand. From their lower ends great quantities of the same coarse debris have been poured down the slopes. For some distance from the base of the crag, the ground is roughened all over with blocks that have come from its mouldering cliffs. There could not be the least doubt in any one's mind that all this rubbish must once have formed part of the crag, that it has been detached in the course of long centuries by the working of the elements, and that the face of the crag must consequently be slowly retreating. If the innumerable blocks of stone that lie strewn about could be put back to the places from which they fell, no doubt many of the existing clefts and recesses on the front of the crag might be filled up.

60. But only a small portion of what has been broken from the crag by the weather now remains at its base. A prodigious amount has been removed, and a little closer examination may teach us how this removal has been effected. At the base of the slope below the crag, the bed of the little brook will be found to be strewn with pieces from the crag. Were we to descend the course of such a

brook, and examine the stones in its channel, we should learn how part of the substance of the crag is disposed of. The bits of stone strewed about upon the slopes above are all more or less angular in shape, that is to say, they have sharp edges. But those a little way down the brook are not quite so rough nor so sharp-edged; and the farther down we go we find the roughness of surface and sharpness of edge more and more to disappear. Fewer big blocks are to be seen, and those which do occur are on the whole more smoothed and rounded than those near the crag. Still lower down the valley we may find that the debris of the crag has been reduced to the condition of ordinary water-worn gravel, thrown down here and there by the stream. And it would not be difficult to trace a passage of such gravel into sand, or even into fine silt and mud. Yet if some of this sand were placed under a magnifying glass it would be found to be wholly or partly made up of grains of the same stone, which might be traced through every size of fragment up to the parent crag among the far hills.

61. If it be asked why stones are worn down in this way by lying in the bottom of a stream, the answer to the question will be best found by watching the work of the stream. In fine weather, when the water is low and the current feeble, no one could anticipate how great the power of a stream may sometimes become. Could we see the same stream when heavy rains have filled every gully in the hills

with a foaming torrent, and when every streamlet rushes headlong down its valley, filling its bed to the brim and even rising high on either side, we should be better able to appreciate the power of

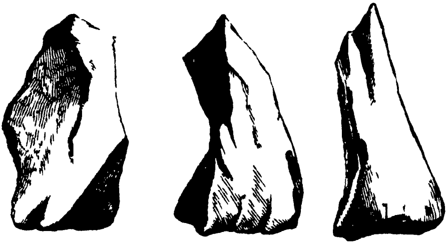

Fig. 6 Angular stones detached from a cliff by rains, frosts, etc., and launched into a brook

running water. The stones on the bottom of the channel are no longer to be seen, but they may now be heard thumping against each other and against the sides and bottom, as they are hurried along by

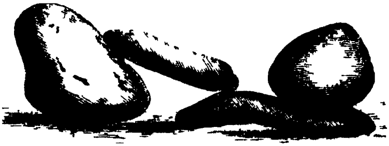

Fig. 7 — Rounded stones from the same cliff after having been rolled about in the bed of the brook

the rushing water They are kept grinding as in a mill Of course they must needs have their edges worn off, and their sides smoothed, while at the same time they grind down and polish the rocks of the channel over which they are driven.

62. The stones first fall or are swept from a hillside into a brook, as mere angular chips (Fig. 6). But by the time they have travelled down the brook a little way, and have suffered from the grinding of a few floods, they lose their sharpness and become more or less rounded, until at last, after some miles of transport, continued, perhaps, during several years, they appear as well-worn gravel (Fig. 7). A rounded stone will travel farther and faster than an angular one, but may in the end be worn down into mere sand (Fig. 8).

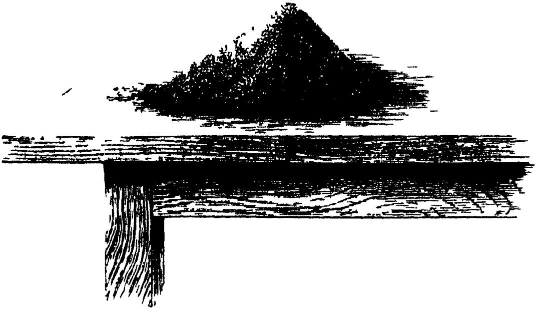

FIG. 8. A small heap of sand consisting of pieces of stone from the same cliff which have been still further worn away in the bed of the brook

63. As the stones grow rounder, they necessarily at the same time become smaller. And as they not only wear away each other, but also grind out the sides and bottom of the channel of the brook, a good deal of stone must be consequently rubbed down into sand and mud.

64. The finer particles, being more easily moved travel farther than the coarser fragments. Hence, while gravel and coarse sand are pushed along the bottom, fine sand and mud are carried along, suspended in the moving water, which may transport them many miles before they can slowly sink to the bottom, there to form a deposit of silt or clay (Fig. 9).

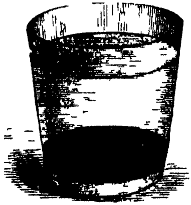

FIG. 9.—A glass of water taken from the same brook when in flood, to show how the finer particles worn from the same stones settle down on the bottom as a layer of mud

65. From the examination of such a stream as has been described here, we perceive that while the brooks in the higher parts of a country may have their channels encumbered with big blocks of rock, and abundance of coarse, sharp, angular rock-rubbish derived from the crags around, this material is worn down by degrees, and reaches the lowlands or the sea only as fine sand and mud. As the brooks are always flowing, so are they always transporting the worn materials of the hills. But as fast as they do so, the crumbling crags and slopes of the hills supply them with fresh materials, so that the amount

of gravel and sand ground up by streams must be enormously great. When we reflect upon the vast number of rivers which, all over the continents, are busy at this task, we cannot but realise that the land is suffering a prodigious waste, and that the sea-bottom must be constantly receiving enormous quantities of sediment. (See Physical Geography Primer, Art. 244.)

66. But it is not only in the beds of brooks and rivers that we may watch how the hardest rocks are ground into gravel and sand. The same lesson may be perhaps even more impressively learnt on a rocky sea-coast. Where a cliff rises from the upper edge of the beach, it is usually easy to tell which parts are exposed to, and which lie beyond the reach of the waves. Overhead the cliff is rough and splintered, where only rain, frost, or springs have acted on it (see Physical Geography Primer, Fig. 8). But towards its base, the rocks have been ground smooth and polished like those in the bed of a mountain-brook. What has smoothed the bottom of the cliff and left all the higher parts rough and crumbling? The answer to this question brings before us the part taken by the sea in the gradual destruction of the land

67. Huge slices of the weather-roughened cliff have been detached and have fallen down on the beach below. Others are ready to tumble off. They have evidently been loosened in the same way, and from the same cause, as in the case of the crag

described in Arts. 58-65. But on examination it will be found that usually only those blocks that lie at the base of the cliff, and have not yet been moved by the waves, still retain their sharp edges. Those that have been moved farther down the beach are more or less rounded, while between them the beach is strewn with stones of all sizes, well rounded and polished.

68. On a calm day, when only little wavelets curl ashore, it is impossible to realise what the sea really does in the way of grinding down solid rocks and loose stones, just as it is impossible to form a proper notion of the work of a brook merely by seeing it lazily creeping along its bed in a season of drought. But could we place ourselves near a cliff during a storm, we should need no further explanation or illustration of the power of the waves to grind down into sediment even the hardest rocks. Each huge breaker, as it comes tossing and foaming up the beach, lifts the stones lying there, and dashes them against the base of the cliff, where it bursts into spray. As the green seething water rushes back again, to make way for the next wave, one can hear, even perhaps miles away, the harsh roar of the gravel, when the stones grate and grind on each other, as they are dragged down the beach, only to be anew caught up and swept once more towards the base of the cliff. We could hardly conceive of a more powerful mill for pounding down rocks into gravel, sand, and mud (Physical Geography Primer,

Arts. 235-237). Along the shores of the sea, therefore, not less than in the channels of torrents, fragments of the rocks of the land may be seen in all stages of destruction, from big angular blocks down to the finest sand and mud.

69. If, now, the question be repeated, "How are Sand and Gravel made?" a clear answer has been supplied in this Lesson. "Sand and Gravel are material worn from the rocks on the surface of the land, and ground down in moving water." Detritus which has been rubbed smooth in this way is said to be "water-worn." But it is not the water which of itself wears them away. They are, in fact, ground to powder by friction against each other and on the rocky bottom, almost all that the water does being to keep them moving and grinding.

III. How Gravel, Sand, and Mud become Sedimentary Rocks.

70. In the inquiry as to the nature and origin of Sedimentary Rocks we are now in a position to understand whence the materials of these rocks were derived. The further question remains for consideration, how these materials have been gathered together and hardened into solid stone. As before, the answer in this case also must be sought in an examination of what is going on around us. By turning back again to the brooks and sea we shall find this next part of the inquiry made clear and intelligible.

71. Water flows more quickly down a steep slope than over a gentle one; and in flowing more quickly it acquires greater force. If a few pebbles of different sizes are placed on the bottom of a trough of water, it will be noticed that as the trough is gently or rapidly tilted up at one end, they are swept down more by the rapid than by the slow flow of the water. The greater the speed or velocity of a current of water the greater is its transporting power. The velocity depends mainly on the slope; being great where that is steep, and feeble where it is gentle. Hence, as different streams, and even different parts of the same stream, vary much in slope, and consequently in velocity, there must be great differences in the size of the stones which they can sweep along.

72. So long as a current of water moves swiftly, it keeps gravel, sand, and mud from settling down on the bottom. In the experiment described in Arts. 45-47, so long as the water in the glass was kept in rapid motion, the sediment continued suspended in the water; it only sank to the bottom as the water began to lose its motion, the gravel most rapidly and the mud most slowly. This experiment illustrates what takes place in all the moving waters of the globe. A rapid current hurries along not only mud and sand, but even gravel and blocks of stone. As its velocity flags, first the stones and gravel sink to the bottom as a sediment, the sand falls more slowly and is consequently carried farther,

while the mud hangs in the water for a long time, travels a much greater distance, and only descends with extreme slowness to the bottom.

73. The truth of these statements should be verified at every possible opportunity by an examination of the rocky channels of brooks, which are in one place steep, at another nearly level, and where there is plenty of gravel and sand to illustrate the transporting work of water. In such situations, it will be found that where water shoots swiftly over ledges and rocks, it has strength enough to sweep even big blocks of rock along with it. Below the rapids, the bed of the stream is strewn with large boulders and coarse gravel, which are dropped as soon as the water, by coming from a steep to a more level part of its course, loses some of its velocity, and consequently carrying power. The finer sorts of sediment are not to be found lying on the steepest parts of the channel; but where the declivity becomes gentle, the stream begins to drop its sand, and advancing into the plains, allows fine silt and mud to settle down.

74. After making observations of this kind with our own eyes, we should be convinced that beds of gravel tell of strong currents of water, that beds of sand point to less rapid currents, while sheets of mud show where the water has had either a very gentle motion, or has been quite still. These conclusions would be based on experience. Nature always works uniformly and consistently, so that

when we find a certain result brought about by a certain cause, we are justified in believing that this is nature's plan which has always been followed.

75. Now see how important such deductions, based on actual observation, become when we begin to inquire how different rocks were made. If we have ascertained clearly how various kinds of sediment are formed, we have advanced some way towards understanding how sedimentary rocks came into existence. Many of these rocks are hard stone now, such as may be used for paving streets or building houses. But we have learnt that mere hardness or softness goes for little, and that it is the materials or composition of the stone that must be considered. Whenever we meet with a stone that is made of water-worn grains of sand, or gravel, no matter how hard it may be now, we feel sure that it was once in the state of mere loose sediment under water.

76. But further, the kind of sediment of which a rock is made up affords some information about the nature of the water in which the materials of the rock were laid down. For instance, a block of conglomerate is manifestly only a compact mass of gravel, about which we may confidently infer that, like ordinary gravel nowadays, its materials were rolled about in shallow water, such as the bed of a lake or river, or on the shore of the sea. Again, a seam of shale may be regarded as having been

deposited in deeper or stiller water, into which finer silt was carried.

77. Having now observed how sediments are formed and transported by brooks, rivers, and waves, we must trace what becomes of these materials when they are at last gathered into places where they can accumulate without being constantly washed away. Some account of this subject will be found in the Physical Geography Primer, Arts. 182-186, where it is shown how, after being washed down by rain into brooks and rivers, the particles worn from the surface of the land are finally borne away out to the bottom of the sea.

78. Such deposits of sediment over the sea-floor will by and by become hard sheets of stone, that is to say, they will harden into sandstone, shale, or some other common kind of Sedimentary Rock. Though we cannot see what goes on under the sea. we may form some notion of it by watching what takes place in pools of water. At the bottom of a gently sloping road, the pools that form in wet weather may serve to illustrate how sediment is disposed of. Following the course of one of the rain runnels down the slope, we notice how the muddy water sweeps along sand, gravel, bits of cork, stick, paper, and whatever lies in its way, until it discharges itself into a large pool that has gathered on the road. So long as the water flows quickly downward, it sweeps away gravel and sand. When it begins to flow more slowly over the flat at the

bottom and enters the pool, it loses carrying power, and must needs drop some of its burden of sediment. The heaviest particles fall to the bottom first, and this takes place just where the current is checked by meeting the level water of the pool. That part of the pool where the current enters is gradually filled up, except the channel which the current keeps open for itself. A tongue of sediment advances upon the water, and will in the end, should the rain last long enough, fill up the pool, except the winding channel of the stream. While the coarser sand is dropped at the upper end, the finer sand and mud are carried across the pool, partly sinking to the bottom and partly escaping in the muddy water that issues at the lower end. The water has not time, in its passage from the one end of the pool to the other, to drop the whole of its burden of mud.

79. When the rain has ceased, should no cart-wheel or other intruder disturb the pool, the water will quietly soak into the ground and evaporate until the hollow is laid dry. Examining now the bottom of the pool, we can see exactly what took place under the muddy water. At the upper end is the tongue of sand pushed out from the shore by the streamlet. Though on a miniature scale, it is a true Delta (Physical Geography Primer, Art. 185). The bottom of the rest of the pool is covered with fine muddy silt or sand spread out more or less evenly over all the space on which the water lay.

80. With a knife we carefully cut a hole or

trench through these deposits on the floor of the dried-up pool, so as to learn what they consist of from top to bottom. A cutting of this kind is called a **Section**, and may be of any size. The steep side of a brook, the wall of a ravine, the face of a quarry or railway-cutting or line of cliff, are all sections of the rocks.

81. In the centre of the little basin, the sediment brought in by the rain has accumulated to a depth, let us say, of an inch, below which lies the surface of the roadway. In looking more narrowly at the section, probably the first feature to strike the eye is the evidence of arrangement in the muddy deposit. If we make a drawing of the section it may be something like Fig. 10. The materials have been deposited in flat layers, one above another, some finer, others coarser than the rest. The coarse sediment is seen chiefly at the bottom. Following out the reasoning already explained (Art. 74), we may infer that it tells of a stronger current at the beginning of the rain-storm, whereby sand and bits of stone were swept across the pool. But as the rain slackened, the runnels on the roadway grew less, and the currents in the pool became feebler. Hence, instead of coarse sand, only fine silt was then laid down. This order of events is clearly recorded in the little section of the deposits; in the upper half, the layers of sediment are finer than they are in the lower. Together with the sand, gravel, and mud, chips of wood, leaves, and twigs (*c* in Fig. 10) may perhaps

be noticed which were borne along by the running water and have found a place among the layers of sediment.

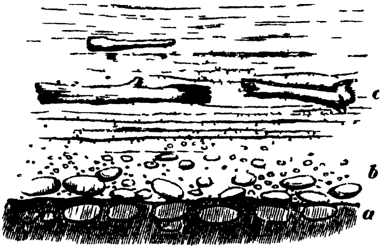

FIG. 10 —Section or cutting through the sediment brought by rain into a pool on a roadway *a* Surface of roadway *b* Layers of coarse sand with bits of coal and ash *c* Layer containing twigs, bits of straw, leaves, paper, etc

82. Observations such as these may perhaps be thought too trifling. The work done by rain in a little pool on a roadway may seem altogether too insignificant to form any foundation for judging what takes place in this world on a great scale. But the scale on which the operations are conducted matters comparatively little. The great aim before us should be to see with our own eyes how nature works. We do not all enjoy opportunities of seeing this on a large scale. It is therefore of the utmost importance, and a most gratifying encouragement, to be assured that if we attentively observe and understand what takes place around us, even on a small scale, we gain more solid knowledge than we should by merely looking wonderingly at the larger operations, with-

out attempting to see how they are produced. It should also be remembered that when the workings of natural agents can be studied on a small scale, they are often much more easily examined, and are therefore, for purposes of education, more useful than where they are displayed in great magnificence. Hence, if we scrutinise and thoroughly master what takes place over the bottom of a pool of water into which rain has swept sediment from the ground above, we lay a foundation from which it will be possible to understand how sedimentary rocks are and have been formed all over the world.

83. Instead of the pool we have supposed, imagine a great lake, such as that of Geneva, and in place of the mere tiny runnel on the road, formed by sudden rain, and disappearing when the rain ceases, picture a great river, like the Rhone, ever fed by the rains and snows and springs of a huge mountain chain. There may seem to be no analogy whatever between the pool and the lake. We look with wonderment on the river rushing so swiftly past, and tossing its muddy waters into wave and foam, from bank to bank. We watch it enter the lake, and mark how the waves one by one sink down, and how the river loses itself and its tumult in the quiet, silent water of the deep blue lake. But if we climb one of the mountains which rise steeply from either side of the upper end of the Lake of Geneva, and, from a height of a few hundred feet, look down upon river and lake, we can hardly fail to recognise a

strong likeness between them and such a runnel and pool as we have been studying. The bottom of the valley lies spread out as in a map before us, —the windings of the river, the flat green meadows on either side running as a long tongue into the lake, the little cottages and hamlets, and the lines of road—all so dwindled down in the distance that we can see them as in a map. That green tongue of meadows filling up the upper end of the lake and stealing along each side of the river is the Delta. It has been formed in the same kind of way as the little delta in our pool, only instead of hours it has needed thousands of years for its formation. About a mile and a half from the edge of the lake, a little hamlet, standing among the level fields, was actually a harbour at the margin of the water some eighteen hundred years ago, and is still called Port Vallais. The river has thus pushed out its delta and filled up the lake for a mile and a half since Roman times.

84. From the high ground overlooking the head of the lake, we can, in some sort, see how the sediment gathers over the bottom. The Rhone is very muddy, and as its mud has a white colour, the milky look which it gives to the water, enables the eye to follow the course of the river into the clear-blue lake. Looking down upon it from the heights we can trace the pale muddy current for some way out from the shore, until gradually mixing with the lake water it disappears.

85. Descending now to the lower end of the lake, let us watch where the water escapes. Not a trace of muddiness can there be seen. On the contrary, our eyes never looked on clearer, brighter, bluer water than that which comes rushing and leaping between the banks and beneath the bridges of Geneva. What has come of that cloud of pale mud which we saw carried by the river into the upper end? It has all settled down upon the bottom. Day by day, year by year, and century after century the cloud of mud is there, always sinking through the water to the bottom, and always renewed by the restless river.

86. Were all the water of the lake drained off, the floor would be found to be covered with deposits of sediment. The coarser shingles and gravels would be met with at the upper end, where the strong current flows, and likewise at the sides where torrents from the mountains enter the lake. The finer sediments—sand and mud—would cover the main part of the bottom. These sedimentary accumulations would be thickest towards the upper end of the lake, that being the quarter from which they had been mainly derived.

87. Were borings made through them, these accumulations would be found to be perhaps several hundred feet thick in the delta. Everywhere they would present the same kind of arrangement into flat layers which was observed in the rain-pool. Sand, mud, and gravel would follow each other in

beds or layers, lying one above the other from the bottom to the top.

88. The Lake of Geneva, though many thousand times larger than our little pool, is yet itself only a small pool, compared with the great sea. At the margin of the sea where a large river enters, we may learn an impressive lesson that mere size does not alter the kind of work which river and sea are doing, and that in their case too the same process has to be studied which we have watched already. The river is continually carrying vast quantities of sand and mud into the sea. We may be able to follow the muddy river-water to a distance from the shore, until, as its mud slowly sinks to the bottom, it loses itself in the waters of the ocean. The bottom of the sea, for a long way from the coast, is in this way constantly receiving fresh deposits of sand and mud which have been washed off the land. The upper edge of these deposits is uncovered when the tide goes out. We may dig into them where they form the beach, and in so doing will recognise the same arrangement into layers as in the pool and the lake.

89. From these various observations and the conclusions to be deduced from them, we should be convinced that one leading feature of sedimentary deposits laid down under water is that they are not mere random heaps of rubbish, but are assorted and spread over each other in regular layers. This kind of arrangement is called **Stratification**, and the sediments so arranged are said to be **stratified**. So

characteristic is this mode of arrangement among the sedimentary rocks that they are often called also the **Stratified Rocks.**

90. The sheets of sand, gravel, or mud which can be seen on the sea-shore, or at the margin of any lake or pool on land, are soft or loose materials. Sandstone, conglomerate, shale, and other sedimentary rocks are usually more or less hard or compact. In spite of their firmness, however, there cannot be any doubt that these rocks were once mere loose sediment, formed under water in the same way as sediment is made everywhere at the present day. What, then, has turned them into hard stone?

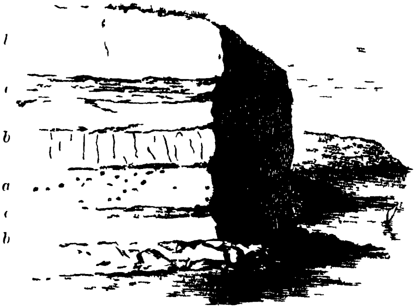

FIG. 11.—Stratification of Sedimentary Rocks. *a* Conglomerate. *bb* Sandstone. *cc* Shale.

91. If some mud be placed under a weight which will squeeze the water out of it, it will be found to become firmer. It is hardened by **pressure.** Again, if some sand be covered with water saturated with

lime (that is, the material of which chalk and limestone are made), or with some other mineral which can be dissolved in water, the water as it slowly evaporates deposits its dissolved material round the grains of sand. Were more of the same kind of water afterwards added from time to time to make good the loss by evaporation, it would be found at last that the grains of sand were bound together by the mineral matter deposited round them. The loose sand would, in short, be changed into a more or less coherent stone. In this case the hardening of the sediment would be done by the process called **infiltration.**

92. In one or other or both of these ways, most of the sedimentary rocks have been hardened into the state in which we now find them. When sand and mud are piled up over each other in wide sheets or layers, to a depth of hundreds or thousands of feet, the enormous overlying weight squeezes them into a firmer condition, while their individual particles may be cemented firmly to each other by mineral matter which has been deposited round them, usually by the water in which they were originally deposited, but sometimes by water which has subsequently percolated among them.

93. Summing up the particulars which have now been given we may describe a Sedimentary Rock as follows:—" A rock formed of sediment derived from the waste of older rocks, and deposited in water. It usually shows the stratified arrangement character-

istic of water-formed deposits Since its deposition it has usually been hardened into stone by pressure or infiltration."

IV. How the Remains of Plants and Animals come to be found in Sedimentary Rocks.

94. Although Sedimentary Rocks consist of such materials as gravel, sand, or mud, they often contain the remains of former plants or animals, which are

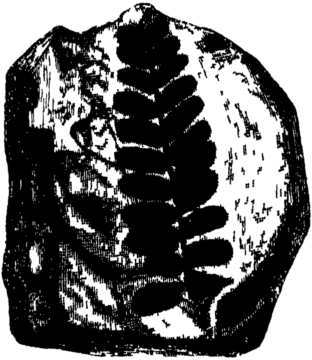

FIG 12.—Piece of Shale containing portion of a fossil fern

of the highest importance in Geology. For example, on the two additional pieces of Shale (Figs. 12 and 13), certain objects, very different from the ordinary sediment of which the stone is made, may be observed. These are **Organic Remains or Fossils.**

95. It is evident that the occurrence of such objects as these gives quite a new interest to Sedimentary

Rocks. How did they find their way into the rocks, and what light do they throw upon the way in which the rocks were formed? The rock represented in Fig. 12 is merely a fragment of common shale, formed of the same materials and arranged in the same stratified way as in the previous specimen (Fig. 5). At the first glance, we recognise the object on its surface to be a plant, and on looking at it more closely, and tracing the form and arrangement and delicate veining of the frond, we cannot doubt that this plant was once a living fern. It has been changed into a black substance which, on further examination, proves to be a kind of coal. Little fragments and layers of the same black coaly substance may occur throughout the piece of shale. If we scrape a little off and put it upon the point of a knife in the flame of a candle or of gas or in a hot fire, we can burn away the black material, while the grains of sand or clay remain behind. These fragments and layers of coaly matter are evidently only leaves and bits of different plants imbedded at the same time as the larger and better preserved fern. Now how did plants find their way into the heart of a piece of stone?

96. To understand how this happened we must turn to what is taking place at the present time. As we watched the runnel coursing down the sloping roadway (Art. 78), we noticed that it sometimes swept along bits of straw wood, paper, or other loose objects, some of which floated away into the

nearest drain and were soon lost sight of, while others sank to the bottom of the little pool. In the section we cut open there (Fig. 10), little chips of wood or straw, or leaves and blades of grass, may not improbably be noticed among the fine sand and mud left by the rain. These objects lie flat between the thin layers of sediment, that being the position they would naturally take as they sank to the bottom. Rain, therefore, may wash away leaves and other pieces of plants, and allow them to drop in a pool, where they are **interstratified** with the sediment there—that is, are deposited between the layers of sand, mud, or silt, and covered over by them.

97. Again: along the banks or at the mouth of a river, we may readily observe that leaves, branches, and other floating objects carried down by the current, sink by degrees to the bottom, there to be imbedded in and gradually covered up by the growing accumulation of sand and mud. At any excavation in the deposits along the banks we may meet with layers of leaves and twigs, grouped along the planes of deposit of the stratified sediment. Such deposits of drifted vegetation often play a conspicuous part in the accumulations that form the delta of a river.

98. But it must happen continually that, before the leaves, branches, or trunks of trees have become so water-logged or saturated as to sink to the bottom, they are borne onward into the sea. In such cases they may float a long way from shore ere they

to the bottom, and are there buried in silt and sand. Hence, whether on the beds of rivers, or at the bottom of lakes or of the sea, the remains of land-plants must be constantly dropping among the sedimentary deposits of the present time.

99. Passing now to the sedimentary deposits of former times, we can have little difficulty in understanding how pieces of ferns or any other kind of land-plants should be found in the heart of a solid stone. The stone, though now so compact, was once merely so much soft sediment laid down below water, and the fragmentary plants were blown or washed away from the place where they grew, until at last they were buried in that sediment. As the original mud hardened into shale, the plant was more and more altered, until its substance passed into coal. It will be shown in a later lesson that coal was formerly vegetation which, buried under great masses of sediment, has been slowly changed into the black glossy substance so familiar to us.

100. It is not only plants, however, which occur imbedded in sedimentary rocks. Here, for example (Fig. 13), is a drawing of a piece of shale containing a number of shells and other animal remains, chiefly *trilobites*, that is, little sea-creatures belonging to the same great tribe with the common crab and lobster. In endeavouring to answer the question of how they were entombed, we must try to realise what is now taking place on the floor of the sea.

101. Did you ever look into the little pools of sea-

water left upon a rocky beach when the tide has gone back? How full of life they are! Tufts of sea-weed sprout up in one place, groups of brightly tinted sea-anemones appear in another, periwinkles and limpets cling to the sides, and down at the bottom you may see tiny crabs cautiously creeping out of sight, with many other kinds of sea-creatures moving to and fro, of which you do not know the names. Looking a little more narrowly, you may observe that some of the shells at the bottom are empty, the animals which once lived in them having died, and that broken pieces of other dead creatures lie there also.

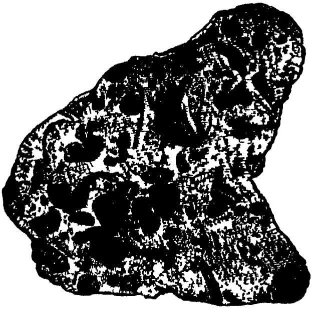

FIG. 13 —Piece of Shale with animal remains.

102. It must not, of course, be supposed that the whole of the bottom of the sea is like the bottom of one of these pools on the beach. The plants and animals in the pools are those which live along the shore or shallow parts of the sea, while the deeper parts have other plants and animals peculiar to them.

But although these living things differ greatly in different portions of the ocean floor, and though, here and there, they may be absent from bare patches of gravel, stones, or sand, and from the deeper abysses of mid-ocean, the floor of the great sea resembles the floor of a little pool on the beach in this respect, that it swarms with many kinds of living creatures, and with the remains of dead ones. So that the deposits of sand, mud, and silt which gather upon the sea-bottom must contain abundant relics of these creatures.

103. If then the remains of plants and of animals are now buried in the accumulations of sediment at the bottom of the sea or of lakes, we may be sure that the same must have been the case in past times. And if this inference be justified, as it so evidently is, then we may expect that sedimentary rocks, which are only so much hardened sediment of the bottom of old lakes or seas, should also contain remains of plants and animals. That they do so abundantly is no doubt already familiar to many readers of this little book who may themselves have gathered specimens of sandstones, shales, and other sedimentary rocks, as full of organic remains as any part of the modern sea-bottom is now crowded with life. Returning to the piece of shale represented in Fig. 13, we infer that originally it existed in the form of fine mud on the sea-bottom, and that in that condition it enclosed and preserved the remains of the organisms that lived and died there.

V. A Quarry and its Lessons.

104. In the foregoing lessons we have learnt what sediment is, how different kinds of sediment, arranged under water, have become sedimentary rocks, and how they may contain the remains of plants or animals. Let us now try to put some questions to these rocks, and see how they may be made to tell their own story.

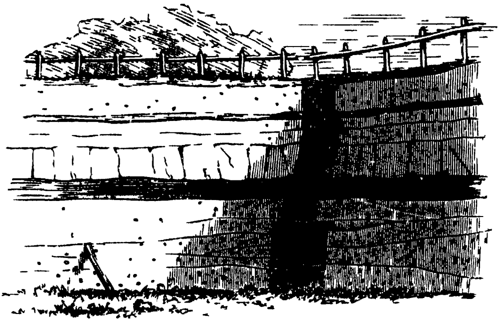

FIG. 14 —Quarry in Sedimentary Rocks.

Much may be learnt from quarries, ravines, or shore reefs, in short, from any artificial or natural exposure where a series of sedimentary strata is laid bare. For the sake of illustration, let us suppose ourselves to be in the quarry represented in Fig. 14.

105. The first feature of the quarry to strike the eye as we enter is the **Stratification** of the rocks. They are disposed in successive bands, one above another, in that stratified arrangement so character-

istic of rocks laid down as sediment under water. (Art. 89.)

106. In the second place, the bands not only differ in thickness and colour, but in the nature of their materials. Of course, no two quarries would be found to agree in these particulars. For the sake of illustration, we may assume that, in our quarry, some of the bands consist of fine conglomerate (marked with little circles and dots in the drawing), others of various kinds of sandstone (marked with finer dots), and some of different sorts of shales or clays (marked with horizontal lines). These **beds**, or **strata** as they are called, alternate with each other, in no definite order, just as gravel, sand, and mud may be found alternating in the deposits that form the delta of a river.

107. In the third place, in regard to the age of the rocks in the quarry, those at the bottom must obviously be the oldest, because they must have been deposited before those lying above them. The lowest bed may be of exactly the same materials and thickness as one or more of the others, and may so precisely resemble them that no difference between them may be perceptible. Yet the occurrence of similar beds, at different levels, one above another, would prove them to be different beds, and to have been formed successively one after the other. In all such cases the beds at the bottom are the oldest, and those at the top the newest. This arrangement of one bed or stratum above another, in the order in

which they were laid down, is called the **Order of Superposition.**

108. This order is, no doubt, very simple and self-evident in the quarry drawn in the woodcut; but it is not always so clear, for in many cases the rocks are concealed in part by soil or otherwise, and much care and patience may be needed before their true order of superposition is ascertained. But every effort should be given to settle which are the bottom rocks and which the uppermost; for when this is fixed, we know which are oldest and which newest, and we can then begin to interpret the portion of the earth's history which they record.

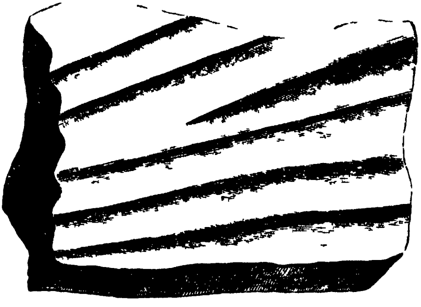

FIG 15 —Ripple-marks in Sandstone

109. In the fourth place, as a further illustration of the way in which geological inquiries are pursued, we may proceed to gather the evidence which the rocks may have preserved regarding the manner and place in which they were deposited. We split open

some of the lower beds of sandstone and find that their surfaces are covered with **ripple-marks** (Fig. 15). Any one who has walked along a flat sandy beach must have noticed the markings which the shallow rippling water leaves on the soft sand, and will at once recognise that the markings shown in the figure are of the same nature. Similar markings may be seen along the shelving margin of a lake, indeed wherever water has been thrown by the wind into little wavelets over a sandy bottom. They generally betoken shallow water. Hence, the first conclusion we draw respecting the origin of the sedimentary rocks in the quarry is, that they were not deposited in a deep sea, but more probably in shallow water.

110. By further search among these strata, we might find some of their surfaces curiously covered with little round pits, about the size of peas or less (Fig. 16). Like the ripple-marks, these markings must have been impressed upon the sand when it was still soft. Again, we must have recourse to what is

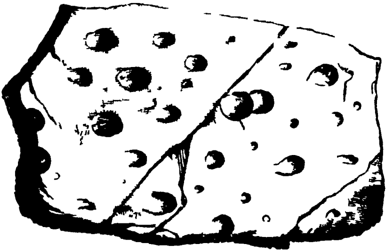
FIG. 16.—Rain-prints on Sandstone.

taking place at the present day for an explanation of what is chronicled among the rocks as having occurred in past time When drops of rain fall upon a smooth surface of moist sand, such as that of a beach, they each make a little dent on it. If the picture of rain-prints in the Physical Geography Primer (Fig. 9) be compared with the foregoing drawing of markings in the sandstone, they will be seen to be essentially similar. There can, indeed, be no doubt that they have both been made by the fall of rain-drops upon soft moist sand.

111. The ripple-marks suggest that the water was shallow; the rain-prints prove that it must have risen along a beach liable, now and then, to be laid dry to the air and rain, and that, during these times of exposure, showers of rain sometimes fell. Now can we tell whether this beach formed the shore of a lake, or of the sea?

112. Again we turn to the rocks themselves, and, from some of the layers of shale, may possibly pick out a number of **fossils**, which enable us to answer the question. An angler who plies his rod in a lake, would not expect to catch the same fish as in the sea. Not only the fishes but the other animals and plants living in fresh water differ from those living in salt water. Star-fishes, limpets, crabs, oysters, and flounders, for example, are inhabitants of the sea, while the trout, perch, minnow, stickleback, and pond-slugs are natives of rivers and lakes. It is quite certain, therefore, that the remains of animals

and plants preserved in the deposits of the sea-bottom must differ from those preserved on the bottoms of lakes.

113. Some of the fossils which we may assume to have been picked out from the shale band in our quarry are represented in Fig. 17. Of these *a* is a coral; *b* is part of the jointed stem of the Encrinite or stone-lily—an animal related to the common star-fish; and *c* is a shell belonging to the Brachiopods or lamp-shells, which are all dwellers in the sea. Now, since such unmistakably marine animals are found associated in a bed of stone, the materials of the stone must assuredly have been laid down under, or at the edge of, the sea. After the animals died, their remains were perhaps washed about on the sea-floor or were possibly cast ashore on the old beach, as shells are at the present day.

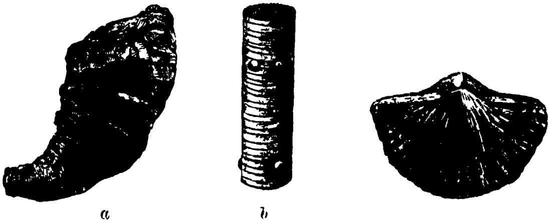

Fig. 17.—Fossils. *a*, Coral; *b*, part of Encrinite; *c*, *Spirifera*, a marine shell.

114. Here, again, is a third fact about the history of the rocks. The ripple-marks and rain-prints showed that the original sediments gathered

in shallow water close to shore, and along a beach; and now the fossils prove that these waters were part of the great sea.

115. In our imaginary quarry, then, we have found clear proofs that land and sea have there changed places. Though the quarry may be in the very heart of the country, far away from the sea, yet the evidence furnished by its rocks proves beyond question that the sea once covered the site. From the South of England to the far end of Scotland, by much the largest number of quarries have been opened in rocks that were originally formed under the sea. Down at the bottom of deep mines, and up at the summits of high mountains, similar rocks are found. By far the larger part of the dry land is formed of them. The highest mountains in the world consist in great part of sea-made rocks.

116. Now is not this strange and puzzling? How has the solid land been chiefly made under the sea? The rocks must somehow have been raised up out of the sea, and since the land is so uneven they would seem to have been raised much more in some places than in others. How this raising of the sea-bed has taken place, will be spoken of in a later lesson (Arts. 173-192). But first we must trace the history of certain other rocks, many of which have also been formed under the sea.

ORGANICALLY-DERIVED ROCKS,

OR ROCKS FORMED OF THE REMAINS OF PLANTS AND ANIMALS.

I. Rocks formed of the Remains of Plants.

117. Since the leaves, branches, and stems of plants, and the shells or other remains of animals, are sometimes scattered abundantly through ordinary sedimentary rocks, they may be expected to occur here and there in such quantity as to form great deposits of themselves. Such deposits could hardly be called sedimentary, in the same sense in which common shale and sandstone are so named. We may term them **Organically-derived Rocks**, because they owe their origin to the accumulation of materials that have been put together by the **organs** of plants or animals. A plant or animal lives, moves, and builds up its framework by means of what are called "organs." For instance, we walk by using our legs, which are *organs of locomotion;* we speak with our mouth, which contains our *organs of speech;* we see by means of eyes, which are our *organs of sight:* and so on. Every object, therefore, which possesses organs is said to be organised, or to be an **organism**; and as only plants and animals are so, the word has come to mean simply a plant or an animal. Fossil plants and animals in rocks are called **organic remains.**

118. We begin with those rocks which have been

formed out of the remains of plants. As an illustration let us examine carefully a **piece of coal.** If we master all that it has to tell, we shall not have much difficulty in tracing out the history of other rocks belonging to this series.

119. The general appearance of coal is familiar in most countries of the world, even where the substance is imported from a great distance. There are various kinds of it, such as gas-coal, steam-coal, household-coal, and others, differing from each other in their qualities for useful purposes, but all agreeing in the essential fact that they have been formed out of vegetable remains. A piece of the bituminous or household variety, ordinarily burnt in houses, is brought to the fireplace in rough, irregular lumps, yet, on examination, it will be observed to possess an arrangement in layers like the sedimentary rocks. A big solid piece of coal usually splits easily in one direction, which is that of its thin layers or "stratification." To make large pieces of coal burn up quickly into a good fire, we should so place them in the grate that their parallel layers shall be more or less upright. In that position the heat splits them up and allows them to burn more rapidly.

120. Now look at one end of a lump of coal, where the edges of the layers are exposed. They are not indeed so definitely marked as those in a piece of shale, for they seem to blend into one another. Most of them consist of a hard, bright, glossy substance, but some are of a soft material

that soils the fingers, like charcoal. No very close observation, therefore, is needed to convince us that coal is stratified.

121. Coal can be burnt away so as to leave only ashes behind, and in this respect resembles wood and peat (see Art. 129). Chemists have analysed it, and found that it consists essentially of the same materials as these substances. Coal, indeed, is only so much vegetation which has been pressed together, and gradually changed into the black substance now used as fuel.

122. Let us suppose ourselves at a coal mine, with the object of seeing how the coal lies, before it is dug out of the earth and broken up into the small pieces which we burn in our grates (see Fig. 37). Descending in one of the cages by which the miners are let down, we reach the bottom of the pit, and after our eyes have become used to the darkness at the bottom, we set out, lamp in hand, along one of the roadways, to reach the place where the miners are at work removing the coal. Now, first of all, we notice that the coal occurs as a bed, having a thickness of a few feet. This bedded character agrees with the appearance of stratification shown by the internal layers in the stone, and further confirms the inference that coal is a stratified rock. We observe further that the pavement on which the coal rests, and the rock that overlies it and forms the roof of the mine, are both made of very different materials from the coal itself. Were a trench or

section (Art. 80) cut through pavement, coal, and roof, it would present some such arrangement as that in Fig. 18, and would prove beyond any doubt that the seam of coal lies among beds of common sedimentary rock (see also Figs. 37 and 38).

123. The floor or pavement on which the coal lies (*b* in Fig. 18) deserves our special attention. It is a bed of dark clay, with abundance of black streaks and branching strings, like roots, which may be traced spreading through it into the bottom of the very coal itself. In other pits and sections, each coal-seam would be found to lie usually on a similar bed of clay or shale. Now why should the coal generally rest on such a kind of pavement rather than on one of sandstone or other rock? We may be confident that the association of the coal with its under-clay cannot be a mere accident, but must have a meaning, which, if found, may help us to understand the origin of coal, and thus to follow that

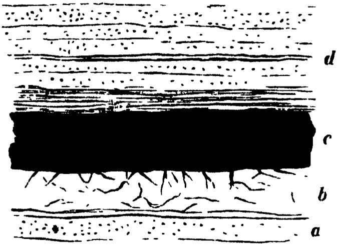

FIG. 18.—Section of a Coal-seam with its roof and pavement. *a*. Sandstones, Shales, etc. *b*. Under-clay forming pavement of Coal (*c*). *d*. Sandstones and Shales, forming roof of Coal.

part of the earth's ancient history which is recorded in coal-mines.

124. Looking more narrowly at the under-clay, we perceive that it resembles a bed of soil with roots branching through it. With this idea suggested to the mind, the more we examine the rock the clearer will this resemblance appear, until we become quite confident that in truth **the under-clay is an old soil, and the bed of coal represents the vegetation which grew upon it** (See Fig. 38.)

125. Each coal-seam has been, in truth, at one time a dense mass of vegetation growing on a wide marshy or watery flat, somewhat like the mangrove swamps along the flat shores of tropical countries at the present day. These marshy plains had a bottom of muddy soil on which the rank jungle grew, and it is this very soil which is still seen in the under-clay.

126. Can anything be learnt about the kind of plants that flourished over these lagoons, and accumulated into the thick mass which formed the coal? Not much is usually to be made out from the coal itself, for the vegetation has been so squeezed and altered that the leaves and branches of the plants can no longer be recognised. In many kinds of coal, parts of the plants have been changed into the sort of charcoal already referred to, which sometimes shows traces of vegetable fibres. There is a method of examining coal and other mineral substances, whereby their minutest structures can be seen. A

thin piece of the stone is ground smooth with emery and water, and the polished face is cemented with Canada balsam to a piece of glass. The other side is then rubbed down, until the slice becomes so thin as to be transparent, when it may be cleaned and placed under a microscope for examination. Some kinds of coal, when prepared in this way, are found to be made up of millions of little seeds, or, as they are called, *sporangia*. These were shed by plants that were akin to the club-mosses of our own moors and hills, but much larger in size. They must have fallen so thickly over the flats as to form a layer, which has been compressed into coal.

127. But though the larger plants have not usually been well preserved in the coal itself, they may sometimes be found in great perfection and beauty in the beds of rock above or below the coal. Some of the common varieties are shown in Fig. 19, the three in the upper line being forms of ferns, and those in the lower being portions of trees, allied to living club-mosses. The last figure to the right hand in the lower row is part of one of the roots with attached rootlets (called *stigmaria*) which are found so abundantly in the under-clays below the coal. The stems and leaves to which these roots were attached have been crushed together to form the coal above. Now and then the plants may be seen lying across each other, in wonderful profusion upon the bottom of the bed of rock that overlies the coal-seam and forms the roof of the mine. Though all squeezed flat, like

dried leaves in a book, they still retain their original graceful forms.

128. Each coal-seam, once a luxuriant growth of vegetation, open to the sunlight, and stretching over many square miles of jungle or swamp, now lies buried deep within the earth, under huge masses of rock, which must be bored through before the coal can be reached. How this burying has taken place is explained in a later lesson (Arts. 193-203). But, before considering this subject, we may with advantage attend for a little to another kind of formation, where vegetation comes into play, and which may be examined not in a deep mine, but in the open day.

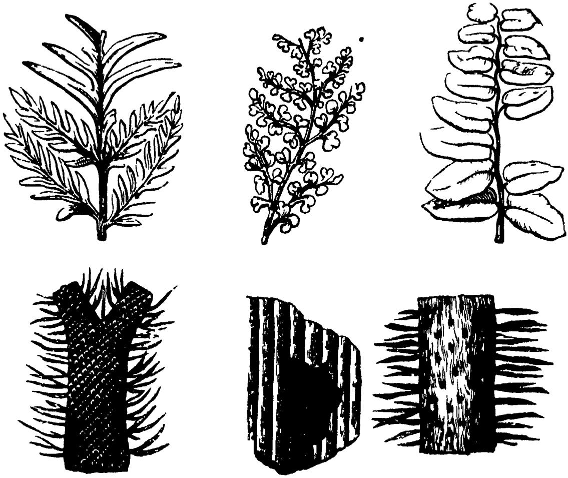

Fig. 19 —Plants out of which Coal has been formed.

129. Most of us have read about, many may have seen, the bogs and peat-mosses so abundant in the northern parts of Europe and of North America. Those who have not, must imagine a wide, flat space of brown moor and green marsh, in many parts so soft and wet that one would sink deep into the black mire if one tried to walk on its treacherous surface; in other parts having a firmer crust, which shakes under the feet of the traveller who crosses the morass by jumping from one dry standing-place to another. Such a flat space is called a bog, moss, or peat-moss. Of the whole surface of Ireland nearly a seventh part is believed to be occupied with bogs, and in many parts of Scotland, Denmark, Scandinavia, and British North America, they occur in great numbers.

130. Visiting one of these places we notice that round its edges it is usually quite firm. It may even have become so dry to the very middle as to be ploughed up and to furnish crops of turnips and potatoes. Wherever we can catch a sight of the substance of which the moss consists, it proves to be a black or dark-brown sort of mould called Peat, or turf, which on closer inspection is seen to be formed of the fibres of plants firmly matted together. Over the whole of the moss this peat extends as a bed, sometimes thirty or forty feet thick. It is entirely a vegetable deposit, and in this and other respects resembles coal. The lower portions are of course dead, but the plants at the surface are alive, so that the peat is gradually getting thicker by the

growth and decay of successive years. In some places a layer of peat three feet thick has been formed in this way during the lapse of thirty or forty years.

131. Such being its composition, peat may, of course, be readily burnt. At the mosses it is dug out in pieces, which are dried and used for fuel. Over great parts of Ireland and of Scotland the peasantry have no other fuel than what they cut every summer from the mosses.

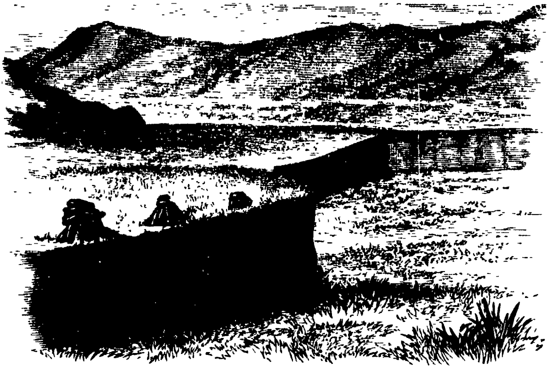

FIG. 20.—Section of a Peat-moss, where the peat is cut and piled into small stacks to dry for fuel.

132. In Fig. 20 a representation is given of one of these cuttings for peat. It is in such places that

the mode of origin of the deposit can best be studied, and as the tracing out of the formation of a peat moss furnishes a good example of the way in which geologists search out the past history of the earth, let us suppose ourselves to be looking into the opening which has been made in the peat-moss drawn in Fig. 20, and to be endeavouring to discover what the history of the place has been.

133. Below the surface of coarse grass and heather lies the peat—a brown fibrous mass in the upper parts, becoming more and more compact towards the bottom, till it passes perhaps into a dark compact substance in which little trace of fibres may be discernible. If the ground has been laid open below the bottom of the peat, a layer of fine clay or marl may possibly be seen, containing, or even entirely made up of, the remains of shells, such as are only found living in fresh water. Now and then a rude canoe, hollowed out of the trunk of an oak-tree, is dug up from the bottom of a peat-moss, together with stone-weapons and other relics of early man.

134. Here, then, in such a peat-moss as we have supposed, there would be most clearly placed before us a piece of geological history. As soon as the separate facts are put together, they are seen to fall naturally into their places, and they reveal to us in a most intelligible and interesting way the story of the peat-moss.

135. The lowest, and therefore the oldest, deposit is the clay or marl just referred to. From what has

been stated in previous pages such a deposit must undoubtedly have been laid down under water. Should it be several feet thick, it will suggest that probably the water was not a mere shallow pool or brook, but had some depth and extent. The shells indicate further that the water must have been that of a lake, for they are such shells as may be found still living in the lakes of the neighbourhood. The first point we settle, therefore, is that before a peat-moss existed here, a lake occupied the site. We may even yet trace what the boundaries of this lake were, for the slopes which rise all around the flat peat-moss must, in the same way, have surrounded the older sheet of water, whereon perhaps our rude forefathers floated canoes like those which are now and then dug up from the bottom of mosses.

136. Above the shelly layer which marks the former lake-bottom, lies the peat, made up wholly of vegetable materials. Evidently the plant remains, by gradually filling up the shallow lake, converted 'it into a peat-moss. In many places this process may be seen actually going on still. In such a peat-moss, for example, as that shown in Fig. 21, it is evident that the little patch of water near the centre is only the remnant of a larger lake, which once covered the whole hollow. At the edge of that remaining pool the marshy vegetation, out of which the peat has been formed, may be observed growing into the water on all sides. A pole put down to the bottom will stir up the fine black or

brown peat, formed out of decayed roots and fibres. There is still some water between the dead peaty matter at the bottom and the growing plants which form a sort of crust over the top. But in the end the accumulated remains of the plants will fill up the whole of this intermediate space, and then even the watery centre will be converted into more or less solid peat, as the outer parts of the moss have already been.

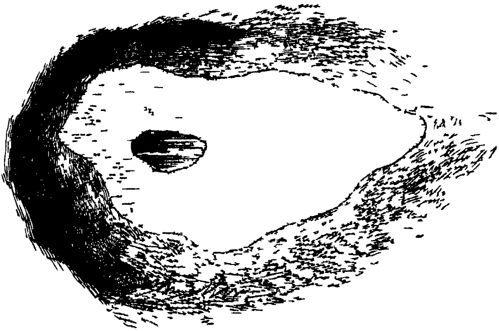

FIG 21.—Ground plan or map of a Peat moss filling up a former lake, and with a portion of the lake still unfilled up

137. We conclude, therefore, that peat-mosses have been formed in marshy grounds or shallow lakes by the accumulation of the remains of marsh-loving plants on the places where, during many years or even centuries, they lived and died. Like coal-seams, peat-mosses prove that, in certain circumstances, the growth and decay of plants may give rise to thick and wide-spread deposits.

II. Rocks formed of the Remains of Animals.

138. At first there may seem to be but little chance that animal remains will accumulate to such a depth as to form a well-marked deposit. Though the air may be filled with insects, though birds in abundance may be seen and heard, as the summer slips away, though in our meadows and woodlands rabbits, hares, moles, and many other creatures live in great numbers, yet we nowhere see their remains forming a deposit on the surface. Nay, we comparatively seldom see a dead animal at all. They creep into holes and die there, and their bodies gradually crumble away and disappear. But if we look in the right places, we discover that the remains of animals, as well as of plants, and indeed much more than plants, form great accumulations.

139. The shells occasionally to be found in the clay or marl under a peat-moss (Art. 133) belong to certain kinds which live in lakes. In some districts the bottoms of lakes are covered with such shells, which, as they die and crumble away, form the white chalky deposit, called marl, which is made up of shells in all stages of decay. The animals so abound in the water that, as they die, their shells form a layer over the floor of the lake. Now and then, such a lake has been either gradually filled up, by being choked with vegetation and silt (Art. 136), or has been drained artificially, so as to be converted into dry land. Its site is marked by the fresh-water

marl, forming a bed or layer several inches or feet in thickness, from which, perhaps, may be disinterred the skeleton of some deer, or wild ox, or other animal, which may have been drowned in the old lake; or the canoe, stone-hammer, or other relic of early human races, that peopled the country before so many of its lakes and forests disappeared. In some districts, where limestone is scarce, the marl of ancient lakes has been dug up in large quantities as a manure for the land.

140. It is on the floor of the great sea, however, that the most wonderful examples occur of the way in which rocks are gradually built up from the remains of animals, to a depth of many hundreds or thousands of feet, and over distances of many hundreds of miles. Something is said on this subject in the Physical Geography Primer (Arts. 238-252); where the use of the dredge for the exploration of the bottom of the ocean is referred to, and allusion is made to the fine **Ooze** formed of minute organic remains, and found over the bed of the Atlantic Ocean. Let us now consider this ooze a little further.

141. To the west of Britain the Atlantic soon and suddenly deepens. Its floor then stretches away to Newfoundland as a vast plain, the surface of which is somewhere between two and three and a half miles below the sea-level. It is over this wide submarine plain that the transatlantic Telegraph-cables are laid, and hence numerous soundings have been made all

the way across from Ireland to the American coast (Physical Geography Primer, Art. 239). In the shallower parts of the sea the bottom is covered with sand, gravel, or mud. The deeper tracts, on the other hand, are overspread with a peculiar gray sticky ooze, which must stretch over the ocean floor for many thousands of square miles. This substance, when dried, looks like a dirty kind of chalk. A minute quantity of it, prepared on a glass slide for the microscope, may be purchased at a mineral dealer's. Looking at such a slide with only the naked eye, we might suppose that the little specks in the centre are merely so many grains of extremely fine dust. But when placed under a strong magnifying glass or microscope they are at once seen to consist of minute shells, called Foraminifera, some quite entire, others broken, and all most delicately sculptured and punctured (Fig. 22). As we look at these graceful forms, it may fill our minds with wonder to reflect that they are crowded together, millions upon millions, in the upper waters of the Atlantic; that as they die they sink to the bottom,

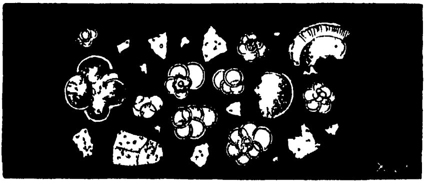

FIG. 22.—Some of the Ooze from the Atlantic bed, magnified 25 times.

where their shells gather into a wide-spread deposit, and that as fresh generations succeed one another, this deposit is continually getting deeper. After the lapse of centuries, if the deposit were to remain undisturbed, and if we could set a watch to measure its growth, we should find it to have risen upward, and to have enclosed the remains of any star-fishes or other sea-creatures which chanced to die and to leave their remains upon the bottom. Hundreds of feet of such slow-formed deposit may have been already laid down over the bottom of the ocean. Here, then, is a second and notable example of how a deep and far-spread mass of rock may be formed out of the remains of animals.

142. If now we return once more to our piece of chalk (Art. 29) and compare it with the ooze of the Atlantic, we may find some curious points of resemblance, which will suggest some new ideas about the origin of chalk. At the first glance, there may be noticed, in many a piece of chalk, a shell, coral, sea-urchin, or other marine organism, either entire or in fragments (Fig. 23). Such fossils as these make it certain that chalk must have been formed under the sea. A little further examination will show that the chalk not merely contains animal remains, but is altogether made up of them. If we were fortunate in the piece of chalk which was treated as recommended in a former Lesson (Art. 29), we found numerous little cases or shells (Fig. 3), quite like those in the Atlantic ooze (Fig. 22), together with

fragments of larger broken shells and other organisms. The whole of the chalk evidently consists of animal remains, some quite perfect, others so broken and crumbled that we cannot be sure to what kind of sea-creatures they belonged. Do not be disappointed if, for a time, none of the chalk which is brushed off shows any distinct organism, but only shapeless white grains. These grains are only the mouldered

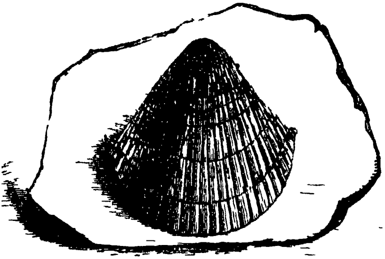

Fig 23 – A piece of Chalk with shell in it

fragments of organisms, and if diligent search be made among them, some still tolerably entire and well-preserved specimens will no doubt be detected. If successful in the search, we may meet with some such assemblage of minute organic organisms and fragments of organisms as is represented in Fig. 3, which is a drawing of a few washed grains of the chalk of Gravesend.

143. Some parts of the sea-floor are so densely crowded with shells, corals, corallines, sponges, and other organisms, that the remains of these creatures

are aggregated into a solid limestone-rock, which spreads over wide areas, and probably grows with comparative rapidity. This modern limestone has been observed to be specially prevalent in the tropical parts of the oceans, where marine currents transport abundant supplies of food. Many ancient limestones have had a similar origin. Here, for instance, is a piece of ancient limestone (Fig. 24), taken from an inland quarry. It has been lying exposed to the air for many years, and its surface has been so etched away by the weather as to present in prominent relief a crowd of fragmentary "stone-lilies," corals, shells, and other remains. The

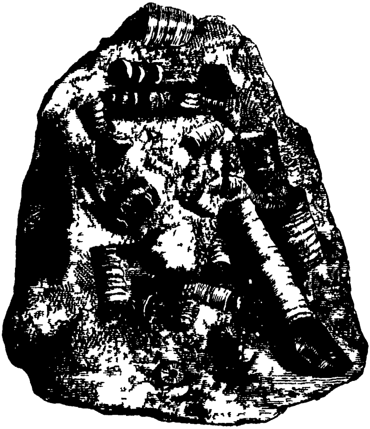

FIG. 24.—Piece of Limestone, showing how the stone is made up of animal-remains.

sight of such a piece of stone as this at once sets us thinking about some old sea-floor. We can picture how all these delicately-sculptured little fragments once formed parts of living creatures which moved or rooted themselves beneath the clear waters of the sea. The bit of limestone becomes in our eyes a kind of model of what a sea-floor must be. It may, perhaps, remind us of what we may even have seen with our own eyes at the bottoms of rocky pools upon a sea-beach. (Art. 101.)

144. If a little fragment of limestone could suggest such thoughts as these, what should we think of ranges of hills, and even mountains, made up of limestone—vast piles of rock two or three thousand feet thick, and stretching over the land for hundreds of square miles? And yet such wonderful masses of limestone, crowded with the remains of old sea-creatures, may be found in almost every country of the world. In Britain, for example, the hills and dales of a great part of Derbyshire and Yorkshire are built up of limestone. In these picturesque valleys, the beds of limestone wind along either side, and rise in broad terraces, one above the other, as far as the eye can reach. In walking along the surface of one of these high hill-terraces, we are really walking on the bottom of an old sea. Everywhere under our feet lie the crowded remains of the little animals which peopled the waters of that sea. Somehow the sea-bed has become dry land, and the thick animal deposits

of its bottom have hardened into limestone, out of which high hills and wide valleys have been formed.

145. Some of the giant mountain-chains of the world consist in great measure of limestone. Among the lofty crests of the Alps, for example, in the chain of the Himalaya, and in the mountain-ranges of North America, limestone, made up of the remains of marine animals, and therefore once a portion of the sea-floor, is found to constitute great ranges of high ground on which rest the eternal snows.

146. **Summary.** Before advancing further, it may be well to look back upon what has now been learnt, that we may see exactly the point to which we have come. A short abstract of the foregoing lessons may be thrown into such a summary as the following:—

(1.) The surface of the land is worn away by rain and by streams, and a vast deal of mud, sand, and gravel is consequently formed.

(2.) This material, worn from the land, accumulates at the mouths of rivers, in lakes, and over the floor of the sea, so as to form great deposits, which will in the end harden into Sedimentary Rocks.

(3.) Leaves, twigs, trunks, and other parts of plants, together with the remains of animals, become imbedded and preserved as Fossils in the sedimentary accumulations.

(4.) Plants and animals of themselves sometimes form thick and extensive deposits upon the surface of the earth.

(5.) The rocks that form much of the dry land have been deposited, for the most part, under the sea.

(6.) Old land-surfaces which, like the coal-seams, once spread out into luxuriant forests, are now buried deep beneath the present surface under masses of solid rock.

147. We have advanced step by step to these conclusions, and are quite sure of them, for we have tested everything on the way by actual observation of the facts. Again and again we have met face to face with proofs that, by some means or other, land and sea have often changed places. We have found old sea-bottoms even up among the crests of the mountains. We have discovered old forests buried, in the form of coal-seams, deep in the bowels of the earth. How can these wonderful changes have taken place? To be able to answer this question, we must learn something about the history of the third or Igneous group of rocks.

IGNEOUS ROCKS.

I. What Igneous Rocks are.

148. The word igneous, meaning literally fiery, though it does not very accurately describe the rocks to which it is applied, has long been in use to include all rocks that have been actually melted within the earth, or which have been thrown out at the surface

by the action of volcanoes. What are called Igneous Rocks, therefore, owe their origin to some of the effects of the great internal heat of the earth (Physical Geography Primer, Arts. 256-268).

149. The first thing to be noted in regard to Igneous Rocks, is their relative scarcity, when compared with the great abundance and wide diffusion of rocks belonging to the other two great classes. In Britain, for example, rocks belonging to the Sedimentary, and the Organically-derived series, are found everywhere from one end of the island to the other. But over considerable spaces not a trace is to be seen of any of the Igneous class. The whole of that part of England which lies to the south-east of a line drawn from Lyme Regis, by Leicester, to Flamborough Head, contains not a single mass of igneous rock, except mere fragments strewn over the surface, which have been transported from the north in a former geological period. And yet, no sooner does one cross into the mountains of North Wales, or into Cumberland, or Scotland, than igneous rocks present themselves in abundance, protruding through the surface, and forming many of the highest and most picturesque hills and crags in these parts of the island. In like manner on the Continent of Europe we may travel from the shores of Belgium across the North of Germany and over the vast plains of Russia without encountering any but sedimentary rocks until we reach the chain of the Ural Mountains. Yet if we take our route from

the North-west of France through Central and South-eastern Europe we shall pass over innumerable protrusions of igneous rocks of many different kinds and of many successive ages. In North America similar observations may be made. In Canada and the Eastern and Central States of the Union there are thousands of square miles entirely free from igneous rocks, while on the other hand in some of the Western States such rocks cover enormous tracts of country. So far, therefore, as concerns geographical distribution, we see that though igneous rocks are not universally diffused, they occur abundantly enough in many places. They have a curious and important history, which forms one of the most interesting chapters in the long record of the changes which the surface of our planet has undergone.

150. In the account given of volcanoes in the Physical Geography Primer (Art. 258), the solid materials cast up by volcanoes are stated to be of two kinds—(1) streams of molten rock called **lava** that flow down the sides of a volcanic mountain during an eruption; and (2) showers of **dust, sand,** and **stones,** which are thrown into the air from the mouth of the volcano, and fall down upon the mountain, sometimes even all over the surrounding country for a distance of many miles.

151. Lava cools and hardens into solid rock. The loose ashes and stones either remain incoherent or are in time pressed together and more or less hardened. Two distinct kinds of rock are thus laid

down upon the surface of the earth by volcanoes. Lava, examined with a magnifying glass, is seen to be made up of distinct **crystals** all matted together. The beds of ashes, on the other hand, no matter how compact they may have become, are found to be made up of irregular **fragments** of various kinds of stone, and of all sizes, from the finest dust up to big blocks. By attending to this simple and intelligible difference we may arrange igneous rocks into two great groups—(1) the **Crystalline**, that is, those which are made up of crystals, and which have consolidated from a melted state; and (2) the **Fragmental**, that is, those which consist of the loose materials thrown out during volcanic explosions.

152. 1. **Crystalline Igneous Rocks.** Granite is an example of one variety belonging to this class. In our former examination of this rock (Art. 27), we saw how greatly it differs from such rocks as sandstone and chalk. But there are many other varieties of crystalline igneous rock. Fig. 25, for example, represents a fragment broken from a current of lava

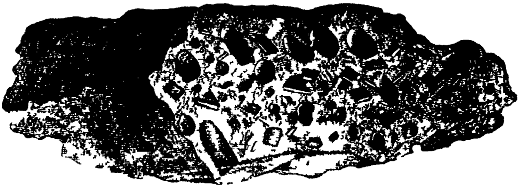

FIG. 25.—Piece of Lava, showing the crystals and the steam-holes

which, when in a molten state, ran down the side of a volcano. Little angular crystals, some of them black and large, others mere white specks, are scattered through the general mass of the stone. A number of rounded cavities may likewise be observed, as if little water-worn pebbles had fallen out of the rock. These holes are important because they prove that the rock was once in a molten state. While in that condition, and still deep beneath the surface, it was full of imprisoned steam and other vapours and gases which, collecting into innumerable little bubbles as the molten mass rose, expanded them into the curious set of vesicles now visible in the consolidated rock. Somewhat in the same way, the holes so often to be seen in the heart of a loaf of bread, were formed by the struggles of the steam to escape from the dough as it was heated in the oven.

153. All lava belongs to this class of rocks. One or two pictures may serve to show some of the more simple and striking features of these lava masses. In Fig. 26 a drawing is given of part of the Island of Volcano, in the Mediterranean, in which the lava that has risen up the inside or throat of the volcanic hill to the edge of the crater (Physical Geography Primer, Art. 259), has run down the outside of the slope. When that took place the lava was, of course, thoroughly molten like liquid iron, and hardened as it cooled in moving. Observe that it has not been able to reach the bottom of the hill. It was, in truth, an insignificant stream, cooling and hardening before

it gained even the foot of the slope But look now at Fig 27 So much more copious a stream of lava has there issued, that one side of the volcanic cone has been broken down by the mass of red hot or white hot lava which has there burst out, and poured down the slope like a black rugged river We can consequently see into the interior of the crater, even from the plain below Each outburst of lava is the escape of a stream of molten rock from the top or the side of a volcano Like an ordinary river of water, it of

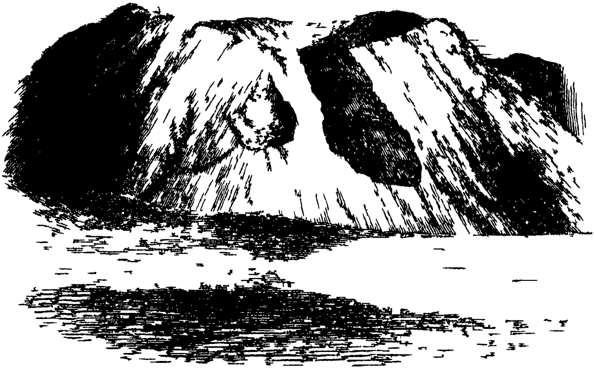

FIG 26 View of the north side of the volcanic cone of the Island of Volcano showing a stream of black lava which has not flowed down to the bottom of the slope

course sweeps into the readiest hollow or valley it can reach, so that, round an active volcano, the valleys are often quite filled up and buried under successive sheets of lava. Like rivers, too, the streams of lava vary greatly in size. That which is represented in Fig. 26 was too feeble to reach the base of the hill, but in the famous eruption of Skaptar Jokul, in Iceland, in the

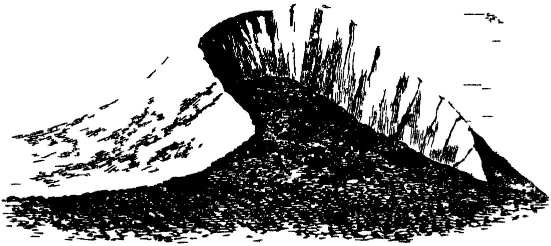

FIG. 27.—View of Lava stream issuing from one of the extinct volcanic cones of Auvergne in Central France. (Scrope.)

year 1783, two enormous streams were poured out, one of them flowing to a distance of forty, and the other of forty-five miles. They ranged from less than seven, to twelve or fifteen miles in breadth, with a thickness of a hundred, and sometimes in confined valleys even six hundred feet.

151. A moving lava-stream is one of the strangest sights in nature. Where it first escapes from the lip of the crater, or from some rent in the side of the

volcano, it glows at a white heat, and flows like molten iron. But a few yards below the point from which it issues, it grows duller and darker, just as a live coal does when it falls from the grate upon the hearth, and the surface of the lava at the same time cools and solidifies so quickly that in a few days we may stand upon it, even though, only a foot or two below, it may still be red-hot, and will set fire to a stick thrust into its crevices. As the mass cools, its movement becomes more sluggish. It looks like a vast heap of cinder blocks, or like the refuse "slags" and "clinkers" from extensive furnaces. Slowly creeping onward, the front of the stream pushes forward, prostrating trees, houses, or other objects in its path, and burying them under its mass. The rough black and brown blocks grind on each other, and roll down the slope with a harsh metallic sound. Steam still rises from many crevices of the lava, and hot blasts of stifling vapours are blown across from it with each breath of wind. Even when the mass has finally come to rest, its inner parts remain still hot for many years, as will be more particularly alluded to on a later page (Art. 171).

155. Could we cut open such a lava-stream from top to bottom, or were we to examine the section of an older one laid bare by a river, we should find that below the upper mass of rough black or dark-brown slag-like lumps, the rock becomes more compact, is commonly dark, almost black in colour, and full of crystals, some of which are extremely minute, others being large

enough to be conspicuous to the naked eye. Some portions we might observe to be full of steam holes (as in Fig. 25), with here and there a large rough cavity, perhaps lined with delicate crystals which had taken form during the slow cooling of the mass. Some lava streams, in cooling and contracting, have assumed a curious and beautiful internal arrangement into six sided or irregular columns. The basalt pillars of Fingal's Cave in Staffa (Fig. 28), and of the Giant's Causeway in Antrim, have been produced in this way. This columnar arrangement may be imitated by putting a quantity of starch in warm water, stirring it well round, and then letting it stand. As the

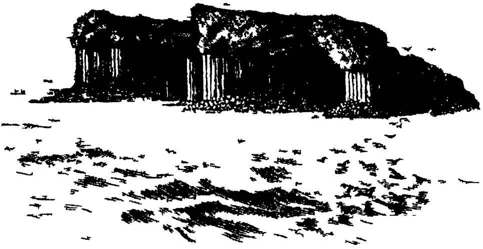

Fig. 28.—View of the Island of Staffa with Fingal's Cave

starch dries and grows solid, it assumes an internal disposition into columns or prisms not unlike basalt.

156. Rocks of this kind occur round the flanks of many active volcanoes, such as Vesuvius or Etna. But they may also be found where the volcanoes are no longer active, as, for example, in Central France, where a great series of extinct volcanoes occurs, of which one is drawn in Fig. 27. Learning to recognise the true characters of lava, we should be able to detect volcanic rocks in hundreds of places where no volcanic eruption has ever been known since human history began. These rocks are witnesses that volcanoes were at work, in far distant times, in districts where perhaps there are now busy cities or fertile fields.

157. For example, though no active volcanoes exist in Great Britain at the present day, they can be shown to have often broken out there in olden times, long before man appeared upon the earth. And not only so, but they can be proved to have been active, now in one part of the country, now in another, during a vast succession of ages. Some of the oldest traces of them are to be met with in North Wales, where not a few of the lava-beds form prominent features in the scenery of that rugged district. Much younger are the sheets and knobs of lava which rise into conspicuous hills across the middle of Scotland. But the latest of the British eruptions were those which, in a long line from Antrim in Ireland, through the Western Islands and the Faroe Islands, away north

into Iceland, built up piles of lava-sheets into what are now vast ranges of terraced hills and table-lands. So, too, in France, though no active volcanoes now exist, abundant remains of them are to be found at intervals from Brittany to Provence. The basin of the Rhine and many regions of South-eastern Europe likewise abound in the ruins of ancient volcanic hills. On the western side of the chain of the Rocky Mountains, enormous volcanic eruptions once took place, though the underground energy has been long quiescent. In Oregon, Washington, California, Idaho, and Montana, a mass of molten rock has been poured out to a depth of 2000 or 3000 feet, over an extent of country estimated to be larger than France and Great Britain put together.

158. But there are other crystalline igneous rocks besides those which rise to the surface and flow out there as molten lava. Granite, for example (Art. 27), is an admirable illustration of the crystalline character. This rock appears not to have been ejected at the surface, but to have crystallized and cooled deep down beneath great masses of other rocks. Yet it now forms bare, naked, lofty mountains. Many of the Scottish Highland hills—for example, Ben Nevis, Ben Macdui, and Cairn Gorm—consist chiefly or wholly of granite. The same rock rises high, too, in the centre of the chain of the Alps, and in the higher mountain-ranges of the globe. Veins or branches may often be noticed proceeding from a mass of granite into the surrounding rocks. These

could not have been formed had not the rock been in a fluid or pasty state.

159. But, it may be asked, if granite has not crystallized at the surface, but under masses of other rocks, how does it come to lie at the surface now, even towering among the crests of bare, lofty mountains? This question is not quite so easily solved, but the way in which an answer must be sought for it will probably be better understood after that portion of these Lessons has been read which treats of the "Crust of the Earth" (Art. 173).

160. 2. **Fragmental Igneous Rocks.** The piece of stone represented in Fig. 29 is a fragment

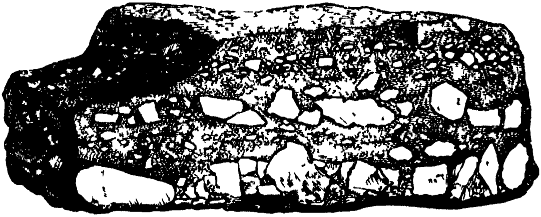

FIG. 29.—Piece of Volcanic Tuff—a rock formed of consolidated volcanic ashes.

from a bed of consolidated volcanic ashes. It is evidently made up of irregular, angular pieces of stone. These are fragments of lava and other rocks, which have been blown into the air by the discharges of the volcano. It is further obvious, from this specimen, that when they fell to the ground and accumulated above each other there, these ejected fragments took a stratified form. The layer of large fragments at the bottom points to a shower of coarser volcanic ashes, while the layers of smaller fragments above show how showers of finer dust afterwards fell through the air. Now this is the kind of material under which the old Roman city of Pompeii was buried (Physical Geography Primer, Art. 262). It fell upon the streets and houses, which, as the eruption of the neighbouring volcano continued, were gradually buried. And at this day, when they excavate the ruins, the workmen find the streets and chambers all choked up with layers of coarser and finer volcanic ash and dust.

161. Of course, if volcanic ashes fall over the sea or a lake, they will settle down beneath the water and form a deposit there. They may cover up and preserve, too, the remains of any plants or animals lying on the bottom at the time of the eruption. This has often happened in past times. In the mountain of Snowdon in Wales, for example, many hundreds of feet of such consolidated volcanic dust still exist, and out of this material one may still pick shells and other marine organisms, which show that the volcanic materials fell into the sea. Again, in Scotland many beds of similar nature are found lying among seams of coal. These masses of consolidated volcanic dust and stones are known by the name of **Tuff.**

II. Where Igneous Rocks come from.

162. It is evident that Igneous Rocks have come up from some intensely hot region within the earth. Of the total mass of our planet, we can examine only

the outer layers, which, though they extend from the top of the highest mountain to the bottom of the deepest mine, form but a small portion of the whole globe. Let us here go over, a little more in detail, the evidence for the great heat of the earth's interior, and the connection between that heat and certain movements and changes at the surface.

163. **Deep Borings and Mines.** At the bottom of a deep mine, the temperature is usually much warmer than near the surface, and, on the whole, the deeper the mine, the greater the warmth. In the same way, when a deep boring is made into the earth for water, a self-registering thermometer, let down to the bottom, shows that a high temperature exists below, and when water rises, it is found to be warm.

164. Experiments of this kind have been made all over the globe, with the result of showing that, at a short but variable distance below the surface, the temperature remains the same all the year, but that underneath that limit, it rises 1 Fahrenheit for about every sixty feet of descent. If this rate of increase continues, we should get uncomfortably hot before having descended very far. For instance, at a depth of about two miles, water would be at its boiling-point, and at depths of twenty-five or thirty miles, the metals would have the same temperatures as those at which they respectively melt on the surface of the earth. It is clear, from this kind of evidence, that the inside of our planet must be in an intensely heated condition.

165. Proofs of another kind lead to the same conclusion. The city of Bath has long been famous for its wells. Now these come out of the earth at a temperature of 120° Fahr., that is, hotter than the water is usually made in a warm bath. And this warm water has been rising to the surface and flowing to the sea ever since the Romans were in the country (for remains of their baths have been found there), and probably long before their time. In many other parts of the world similar **Hot Springs** occur. Iceland, New Zealand, and the Yellowstone Park of Wyoming in the United States, furnish remarkable examples called Geysers (that is, "Gushers"), where, at intervals, the boiling water and steam gush out with a great noise, and rise high into the air (Fig. 30). To keep up hot springs in every quarter of the globe there must assuredly be great stores of heat within the earth.

166. But the heat neither of deep mines nor of hot springs affords such an impressive lesson as to the earth's internal high temperature as is furnished by **Volcanoes**. The hot vapours and steam that rise from the craters of volcanoes, the torrents of hot water that sometimes issue from their sides, the streams of molten lava that break out and roll far down the slopes of a volcanic mountain, burning up and burying trees, fields, gardens, and villages—are all tokens of the intense heat of the inside of the earth from which they come.

167. At the present time there are, it is said,

about 270 volcanoes which, either constantly or at intervals, throw out steam, hot ashes, and lava, in different parts of the globe (Physical Geography Primer, Art 263). Down the whole line of the

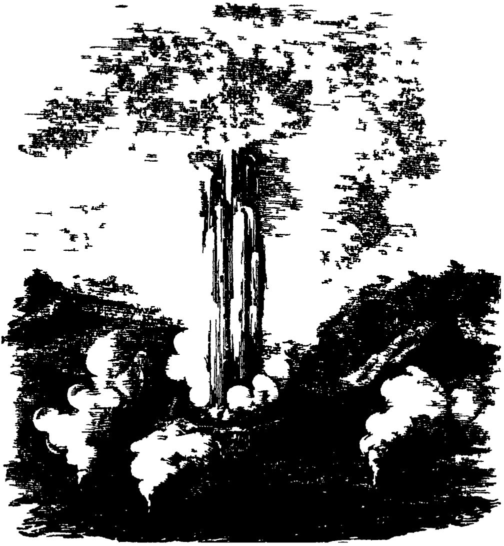

Fig 30 View of Hot Springs or Geysers Iceland

mountains which range along the western margin of the American continent, volcanoes are numerous, some of them of vast height, like Cotopaxi (19,500 feet). From the northern extremity of America they extend, by way of the Aleutian Islands and Japan, to the Malay Archipelago, where in Java they greatly abound From that point they may be traced at wide intervals into New Zealand on the one hand, and on the other through the centre of Asia by way of the Red Sea and the Mediterranean, up to Iceland and down to the Azores, and thence across to the West Indies and the centre of America Even among the perpetual snows of the South Polar regions they have been met with, and also far within the Arctic Circle at the Island of Jan Mayen.

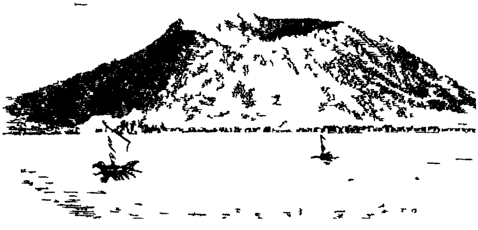

FIG 31 — Vesuvius, as it appeared at the beginning of the Christian era, when it was a *dormant* volcano

168. But besides the volcanoes which are still active, some 400 others occur from which no eruptions have ever been seen to take place, and which are therefore called **dormant** (see Figs. 27 and 31). If we were to mark on a map the position of every place on the earth's surface where, either

now or at some past time, hot gases, steam, ashes, or lava are, or have been, emitted, we should find few countries to be without some trace of recent or ancient volcanic action. A map so marked would show how widespread volcanic action has been, on the whole over the globe, and therefore how powerfully and generally the heat of the interior has manifested itself at the surface.

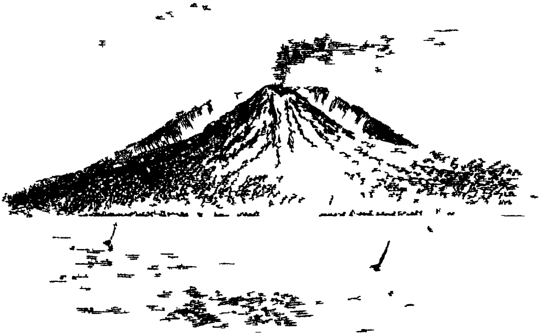

Fig. 3.—Vesuvius as it appears at the present time, an active volcano.

169. But Igneous Rocks do not furnish the only evidence that the internal heat affects the surface of the earth. The more powerful kinds of **Earthquakes** (Physical Geography Primer, Art. 265) are probably to be ascribed to commotions which take their origin from the effects of the loss of heat. As bodies expand when heated, and contract as they cool (Physics Primer, Art. 19), the earth when it

was vastly hotter than now, must have filled more space. Hence, in cooling, it has been gradually diminishing in size. This contraction of bulk probably does not take place continuously and equably, but rather at intervals, in sudden snaps, especially along lines of mountain-chain. Such convulsive shocks give rise to earthquakes, which travel outwards from the centre of disturbance, in wave-like undulations, through the solid crust of the earth.

170. Perhaps the question may be asked why, since the inside of the planet is so hot, does it not melt the outside, or at least why is the outside not warmer? There can be no doubt that, at one time, millions of years ago, the globe was immensely hotter than it is now. In fact it may once have resembled our sun, of which at first it probably formed a part, and from which it and the other planets have one by one been detached. During the vast interval which has passed away since then, it has been gradually cooling, and thus the heat in the inside is only the residue of that fierce heat which once marked the whole planet. The outer parts have cooled and become solid, but they are bad conductors of heat, and allow the heat from the inside to pass away into space only with extreme slowness (Physics Primer, Arts. 64, 65). Hence, in spite of the high temperature of the interior, we are not sensible that it warms the outer surface of the earth.

171. If we reflect upon the history of a lava-stream, we may not find it so difficult to understand

why there should be such a difference between the temperature of the interior and that of the surface of the earth. Lava comes out of a volcano like so much liquid white-hot iron. We cannot go near to it on account of its intense heat, and its bright light is dazzling to look at. (Art. 154.) Yet only at a short distance from where it issues in this intensely hot, glowing, liquid condition, the mass, as already stated, soon becomes black, hard and cool enough on the surface to be walked on. But the inside, below this cool outer crust, may still be red-hot. Could we return to such a lava-stream a dozen of years afterwards, though its surface would be perfectly cold—a mere rough sea of black bristling lumps of rock—yet down in the depths of the mass the heat might still be so great as to supply continual clouds or wreaths of steam, from rents into which one could not put one's hand without having it burnt. Now if a mere river of lava takes so long to cool down to its centre, we need not be surprised that the huge mass of our globe should still be intensely hot inside, even though its outer portions have been solid and cool for long ages.

172. Besides earthquakes above alluded to (Art. 169), other effects of the earth's contraction are visible among the rocks. An enormous pressure or strain is exerted on the outer parts, which, since they are made of such very various materials—Sedimentary, Organically-derived, and Igneous Rocks—yield to the stress more in some places than in others.

And thus, somewhat like the skin of a dried and shrivelled apple, the surface of the globe has been ridged up in one region, and has sunk down in another, besides being squeezed and broken. The evidence that can be brought forward to support these statements will be given in the next Lessons.

THE CRUST OF THE EARTH.

I. Proofs that parts of the Crust have been pushed up.

173. We have now completed the first part of the task which was proposed in an earlier Lesson (Art. 41),—to find out what the materials are of which the great stone floor of the earth is made. We have learnt something about three great classes of rocks which form that floor—how they were made, and where they are to be seen. But while learning these facts about the earth, we have found that the rocks are not a mere thin covering like a wooden floor, below which we should come to something quite different. We cannot get down beneath the rocks. Deep as the deepest mine, the same kind of rocks may be found which elsewhere exist at the surface. It is always through rock of some kind that we must descend, as far as we can penetrate into the bowels of the earth.

174. This solid, rocky, outer part of the earth on which we live, into which men sink mines, and out

of which springs arise, is called the **Earth's Crust.** This name came into use when people supposed the inside of the planet to be an intensely hot liquid mass, with a cool and comparatively thin crust outside. A great deal of dispute has arisen as to whether the main mass of the inside of the earth is liquid or solid, but those who dispute, whatever their view may be, agree to use this phrase, "the Earth's Crust," as meaning that part of the earth which men can observe from the top of the highest mountain to as far below the deepest mine as they can reasonably infer what the rocks must be.

175. The rocks of which this crust consists belong in large measure to the Sedimentary series, abundantly also to the Organically-derived series, while a smaller but still considerable proportion of those which appear at the surface belong to the Igneous series. Deep down below the upper stratified parts, all the rocks are no doubt such as would be classed in the Igneous division. The thickness of those stratified parts is considerable. In Britain, for example, if we could put all the different series of sedimentary and organically-derived rocks together, one above another, in the order in which they were deposited, they would form a mass at least ten or twelve miles thick. Out of such materials the solid land is built, as far down as man has been able to penetrate.

176. But from what has been stated in previous Lessons, it is clear that many rocks are not now in

their original positions. The quarry, for example, which was used to illustrate the way in which stratified rocks are made to tell their story (Art. 104), proved beyond any question that its site, though now dry land, once formed a part of the sea-bottom. Then, again, the coal-seams, buried so deep in the earth, were once verdant forests or jungles at the surface (Art. 128). How could a sea-floor become dry land, and how could a forest, on the surface of the land, be covered by hundreds of feet of solid stone?

177. Let us begin by considering how a portion of the floor of the sea can be changed into dry land. And in order to follow the change as clearly as possible we may choose one of the simplest kinds of proof, of which the shores of Western and North-western Europe furnish many interesting examples.

178. Round the coast-line of the northern part of Britain, and much of the coast of Norway, there runs a succession of shelves or terraces which wind in horizontal lines one above another for mile after mile. One of the lowest of these lines forms a conspicuous feature on both sides of Scotland, where it makes a low flat platform, bounded by the sea on the one hand, and by a cliff or inland slope on the other. Seaport towns have been built upon this terrace, such, for instance, as parts of Glasgow, Greenock, and Leith. It is so level that roads run along its surface for miles, among cornfields, meadows,

and villages. Some notion of its general appearance is given by Fig. 33, which shows how flat it is, and how little elevated above the sea at its outer edge. Along the inner margin there often rises a line of cliff pierced with caves, as represented in the drawing. Standing on some part of this terrace and looking along its level surface, as it winds in and out against the cliffs and slopes of the land, we can hardly fail to be struck by the resemblance of the ground to an old coast-line. We may without difficulty picture the sea covering the terrace and beating against the base of the cliffs and slopes.

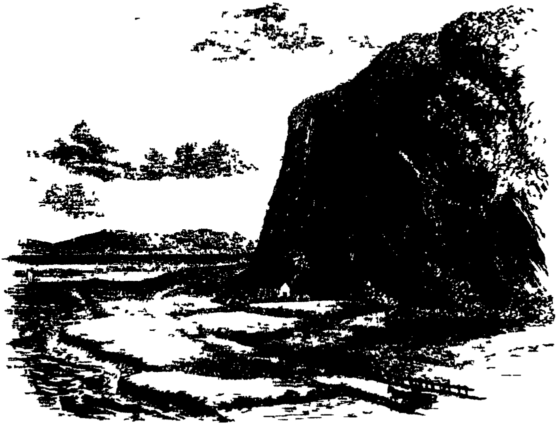

FIG 33.—View of a Raised Beach.

179. Could we prove this idea to be anything more than mere fancy? Let us see. Cross to the

inner margin of the terrace and consider attentively the line of caves there. How were these excavations drilled into the solid rock, all along the same line and exactly at the same level, so that the floor of each of them should just open upon the flat terrace? Festoons of ivy and honeysuckle hang perhaps in tangled luxuriance across their openings, and were we to enter one of them, it might be only after forcing our way through a brushwood of strong briars. Gaining the floor of a cave, we find it roughened with rounded, water-worn stones. The roof is partly hung with ferns, mosses, and liverworts, and the sides too have their drapery of green. But the bare rock appears everywhere, and we notice that it has been rubbed smooth, and has the same water-worn character as the stones under our feet. On the other hand, the rocks of the cliff above are rough and sharp-edged, as year after year they split up under the influence of the weather. The walls of the cave have been ground smooth from one cause, the face of the cliff has been made rough from another.

180. The explanation of this difference will be found on any rocky beach exposed to the swell of the sea. We have already (Arts. 66-68) learnt that the base of a sea-cliff of hard rock, wherever the waves can reach it, is worn smooth by the ceaseless grinding of the gravel and stones. Every cave, into and out of which the waves drive the gravel, is ground down in the same way. A single

forenoon, spent on such a coast-line, teaches a lesson we can never forget as to the way in which rocks have their surfaces smoothed by the waves. But all that part of the cliff which lies above the reach of the breakers, comes under the influence of other forces. Rain, frost, and springs, combine to split and loosen the face of the cliff, and impart to it that rough, angular appearance which contrasts so well with the water-worn rocks below.

181. After having observed what is taking place now along a sea-cliff, and having compared the appearances to be seen there with those exposed along the line of cliff which rises from the inner margin of our terrace, we find them to be so precisely similar as to justify the inference that this line of cliffs once rose along the edge of the sea, and that the waves, beating against its base, bored the line of caves, as they are still doing elsewhere. The line of that inland cliff thus stands forth as a monument, to mark what in some ancient time was the edge of the sea.

182. But further proofs of the former presence of the sea will be found when we put questions to the terrace itself. Beneath the surface of the terrace, sand and gravel, sometimes with abundance of shells, may be observed in every excavation. The outer margin of the terrace, where the sea is gradually cutting it away, exposes a section of the sand and gravel (Fig. 34), which are there seen to have been laid down in layers, just as they are now being

deposited on the beach below. We note that the shells belong to the common kinds which are washed up by every tide upon the sands. We discover that, in truth, the terrace is simply an old beach,

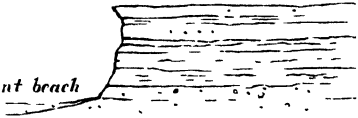

FIG. 34.—Section of a Raised Beach.

and that the sea must have laid down the sand and gravel, when it was scooping out the caves at the foot of the cliff. Thus the terrace and the caves combine to prove a change in the coast-line.

183. By measuring the height of the floor of the caves and the surface of the terrace above the present high-water mark, we can ascertain the difference of level between the present beach and the old one. Let us suppose that this difference is, in the present case, twenty feet; it is plain that the land must have risen, or the sea must have sunk, to the extent of twenty feet.

184. When we watch the restlessness of the sea, with its ever-moving surface, its ebbing and flowing tides, its waves and currents, and contrast with this ceaseless motion the calm steadfastness of the land, we may naturally enough suppose that, in any changes of the relative position of land and sea, it is much more likely that the sea should have shifted its place than that any alteration should have

happened to the land. But we cannot suppose that a change in the sea-level at any place would be confined to that place; it would necessarily extend beyond it. If we deepen the bottom of one end of a pond, the level of the water does not fall just over that part, but is lowered over the whole pond. In the same way, if a quantity of stones and earth be emptied into the pond, so as to make one part much shallower than the rest, the level of the water is not raised only over that part, but uniformly over the whole.

185. What we call the sea-level is not by any means uniform. It may be several inches or feet higher on one side of a country than on the other. There are several causes which may produce considerable variations on its distance from the centre of the earth. One of these causes is the attraction exerted by large masses of land. A great chain of mountains like the Andes draws up the surface of the ocean towards the high land, so that any serious change in the height of a continent would affect the level of the neighbouring sea. Any such alteration of the surface of the sea, however, would not be confined to a limited area, but would affect a wide region. It is possible that in some cases the lines of old sea-margin may be due to an actual sinking of the surface of the sea. But in others where the terraces undergo local diversities of level, they must be explained in another way.

186. Not only do the lines of ancient sea-margin

display inequalities of level, they sometimes die out even in places where they might have been expected to be well marked. They are characterised by a want of uniformity and parallelism which seems to point to some other operation than a rising or falling of the great body of oceanic water. These features are well exhibited in the British Isles. Limited as is the coast-line of these islands, it affords abundant evidence not only that there has not been any general subsidence of the ocean over that region, but that some of the changes of level, which have strikingly affected certain parts of the country, have not extended into others. On both sides of Scotland the ancient sea-margins are conspicuous in many places. But they disappear towards the north, being absent in the Orkney and Shetland Islands, where there are many sheltered inlets in which they would almost certainly have been preserved had they ever existed. Again, along most of the coast-line of England they do not exist, but another group of them at other levels appears along the south coast.

187. If we pass from the Shetland Isles, where the terraces are absent, to the coast of Norway, we come upon another and still more remarkable series. They rise one above another as level parallel lines which wind along the sides of the mountains that rise from the fjords. In the north of the country they occur in great perfection (Fig. 35), up to heights of six hundred feet or more. But the same terrace does not preserve everywhere precisely the

same height above the sea Again, a terrace, conspicuous on one part of a coast line, may be wholly absent at another, where perhaps another at a different elevation may be prominent These variations seem to indicate that the terraces have not been caused by a general intermittent sinking of the sea level, for, in that case, we should expect much greater uniformity among them

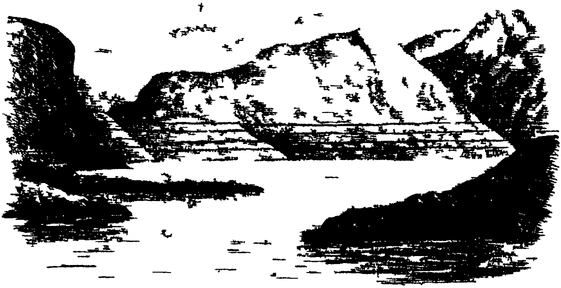

FIG 35 —Terraces (old Sea Margins or Raised Beaches) of the Alten Fjord Norway

188 Strange as the statement may seem, it is nevertheless, in the main, true, that it is **the land which rises**, rather than the sea that sinks On this view of the case, it is easy to see why there should be terraces in some countries and not in others, and why the same terrace may even vary

in height at different parts of its course. For the land has evidently been pushed up at one place and not in others, and more at one place than in another. The old sea-terrace (Fig. 33) is called a **Raised Beach**, because it consists of gravel, sand, and other beach deposits, which have been raised above the level of the sea.

189. Every raised beach points to a former sea-margin, and to an elevation of that sea-margin into dry land. Where a number of terraces occur one above another, as in Norway (Fig. 35), they show that the land has been raised up at intervals for a long period, the time when it was stationary between two upheavals being marked by a terrace or raised beach. Of course the highest terrace must needs be the oldest, and for that reason is often less perfect than the newer ones, having suffered more from the various forces, such as rains, frosts, and streams, which are so busy in making the surface of the land crumble away. (Physical Geography Primer, Arts. 133-147.)

190. In some parts of the world the ground can almost be detected in the very act of rising. In the North of Sweden, for example, rocks have been marked at the place where high-water reached them, and in the course of years have been found to be considerably above their former level. From observations of this kind it has been inferred that the land there is rising at the rate of seven feet in 154 years. This might be thought to be too slow a movement to be appreciated, except by careful measurement;

and yet if it were to go on for a thousand years, what is now the beach would have risen to a height of forty-five feet above the sea-level.

191. The upraising of the bottom of the sea, therefore, strange as it may seem to us, is not entirely a thing of the past. It is going on slowly at the present time in several parts of the globe. And just as the coast of Sweden has been rising with no violence or shock, so in old times the upraising of the sea-bed into dry land may have been a gentle and quiet process.

192. The rocks of every country furnish abundant evidence that the sea-bottom has again and again been turned into land. This evidence is mainly furnished by the remains of corals, star-fishes, shells, and other sea-creatures imbedded in the rocks (Arts. 94-103). The height at which these remains are found above the sea affords some idea of the extent of the uprise. The shells of the raised beach already described (Art. 182) indicated a rise of only some twenty feet. But if we found such sea-shells forming parts of a mountain crest at a height of twenty thousand feet, they would prove that the bed of the sea had been elevated at least to that extent (Art. 113). By this kind of evidence it can be shown that by much the greater part of the dry land has been raised, piece by piece, out of the sea, and that the movements have been far from regular or uniform, seeing that some parts have been upheaved to a much greater height than others.

II. Proofs that parts of the Crust have sunk down.

193. We have now traced out some facts which show that the surface of the globe has from time to time been pushed up, so that parts of the sea-bottom have become dry land. But other movements of exactly an opposite kind have turned parts of the land into the bed of the sea.

194. Along certain tracts of the coast-line of Britain, as, for example, on the coasts of Devon and Cornwall, and on that of the Firth of Tay, between high and low water mark, there may here and there be seen, protruding from the flat sandy surface of the beach, dark stumps, which on closer examination prove to be the lower ends of trees When the sand of the beach is scraped away, dark loam or earth is found below it, in which the tree-stumps lie, and from which we may pick up hazel-nuts, leaves, twigs, and now and then perhaps the wing-case of a beetle, or the bone of some land animal. The stumps are all in the usual upright posture in which trees grow. The dark earth in which their roots spread is clearly an

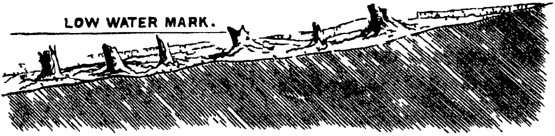

Fig 36 —Section of a Submerged Forest

ancient soil, in which to this day may be gathered the very leaves, twigs, and nuts that fell from the trees, and fragments of the insects that lived amid their decaying timber. We have evidently here before us the remnants of an old forest or piece of woodland.

195. But could the trees ever have grown at the level at which their remains are now to be seen? By no means. The hazel, birch, alder, and oak, of which the stumps mostly consist, would be killed if their roots and trunks were to be permanently submerged in the sea. None of these trees is ever to be seen growing below tide-mark now, and we cannot suppose that they ever did grow there. If they must have lived on the spot where their remains still exist, and if they could not have grown up in the sea, then, either the sea must have risen up so as to cover them, or the land must have sunk down so as to submerge them. But we have already learnt (Art. 188) that in such cases of change of position, though the sea may sometimes alter its level to an appreciable extent, such limited effects as the local submergence of the trees should rather be ascribed to a sinking down of the land. These **Submerged Forests**, therefore, may generally be regarded as evidence of subsidence of the earth's surface, just as raised beaches are taken as proofs of upheaval.

196. A little reflection will convince us that it must be more difficult to trace evidence of ground having sunk, than of its having risen in level. That

this must be the case, will appear if we consider that when any district is undergoing submergence below the sea, the waves gradually obliterate the characteristic features of the land-surface, especially the soil with its mantle of vegetation, as the submerged forests are now being slowly washed away; while, on the other hand, when the bed of the sea is turned into dry land, such traces as raised beaches, and old sea-worn caves, being placed above the reach of the waves, remain to mark the space which the salt water once covered.

197. In different parts of the globe, it has been observed that the sea appears to be gradually rising upon the land. For example, the southern part of Greenland for several hundred miles has during the last few centuries been slowly subsiding, so that rocks which once lay above the limits of the tides are now submerged, and the dwelling-houses of the inhabitants have required to be shifted farther and farther inland.

198. Other proofs of the same fact have already been referred to in the foregoing Lessons. Beds of coal, which once flourished as green forests at the surface, are now found buried deep within the earth (Art. 122 and Fig. 18). By what process did they get there?

199. Coal-pits are often more than a thousand feet deep. Could we look at all the rocks which have been cut through in making the long shaft of a pit, we should probably find among them other coal-seams

than the one which the colliers are excavating at the bottom. In fact, several seams are sometimes worked at different levels in the same pit, as represented in the section in Fig. 37, which shows how the rocks lie one above another. The seam down to which the shaft has been sunk in this pit is the fifth of the series, but it has been chosen probably because it is a better kind of coal than the other four seams above it, and brings more money in the market.

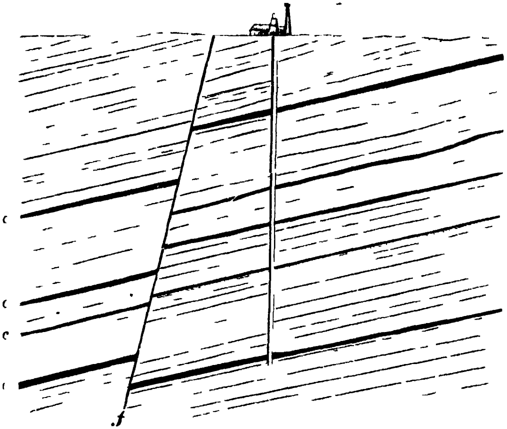

FIG. 37.—Section of the Strata in a Coal-pit. c, Coal-seams; *f*, a fault or fracture of the rocks.

200. Such a section as that in Fig. 37, representing what may be met with in any coal-field, reveals a strange series of revolutions in the geography of the region, whereby successive forests have been buried

underground. Each separate coal-seam was evidently at one time a verdant plain, open to the sun, and bright with many a graceful tree and fern. But they have all been buried, one after another, under thick sheets of sandstone and shale. Moreover, upright stems of trees, now turned into stone, are sometimes found in the sandstones and shales, standing in the position in which they grew, with their roots imbedded in the ancient soils. (Fig. 38.)

201. The lowest strata are of course the oldest (see Art. 107). Hence the undermost coal-seam must have been buried before the later forests could spring up on its site. It grew probably in a wide, marshy plain, or a lagoon of shallow water, during a time when the region was slowly sinking below the sea—perhaps with intervals when the subsidence for a time ceased. Sand and mud, carried into the water from some neighbouring land, were laid down upon the submerged forest, and form now the beds of sandstone and shale which overlie the coal-seam. The sediment brought into the wide and shallow lagoon would, in the end, raise the muddy bottom up to the surface, and thereupon a new mass of vegetation would take root, and another luxuriant growth would provide material for a second seam of coal. But thereafter, the downward movement of the ground again showed itself, for the second forest was submerged under renewed accumulations of sand and mud. Hence each coal-seam seems to mark a time when subsidence had nearly or entirely

ceased, and when a thick growth of vegetation spread over the swamps, while the sandstones and

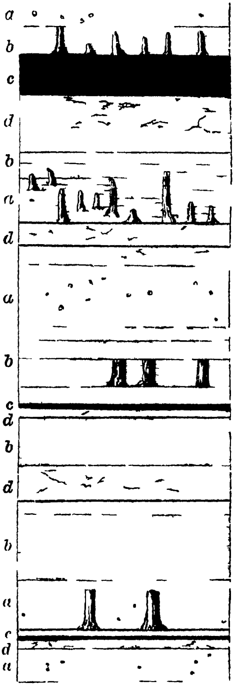

FIG. 38.—Section of a part of the Cape Breton Coal-field showing seven ancient soils with remains of as many forests (R. Brown). *a*, Sandstones; *b*, Shales; *c*, Coal seams; *d*, Underclays or Soils.

shales indicate a renewal of the downward movement and a fresh inpouring of sediment.

202. It thus appears that our coal-fields were

formed in sinking regions, and that the downward movement was not continuous, but went on at intervals. That it must have been prolonged through vast periods of time is apparent from the fact that the strata of the coal-fields are several thousands of feet thick, and must have needed long ages for their formation.

203. Two facts are now clear to us about the crust of the earth—(1) parts of it have often been pushed outwards, so as to rise above the level of the sea; and (2) parts of it have also often sunk inwards, so as to carry tracts of the land beneath that level. But it could not undergo these movements without suffering other changes, which will be considered in the next Lesson.

III. Proofs that the Rocks of the Earth's Crust have been tilted, crumpled, and broken.

204. If we consider that the crust of the earth has often been pushed up and let down, we shall not be surprised to find that the rocks have not only been shifted up or down, but have been crumpled up and broken across. Hence the crust of the earth, instead of being made of regular layers one above another, like the coats of an onion, has been so squeezed and fractured, that in many cases the bottom or oldest rocks have been pushed up far above the newest.

205. Clearly to follow the proofs of these great terrestrial movements, let us begin with a simple

case, by turning back to the view and section of the Raised Beach in Figs. 33 and 34. The sand and gravel beds, once below high-water mark, now rise well above it, but they have not otherwise been disturbed. They still lie horizontally as they used to do. But would this be the case everywhere along that terrace? We found (Art. 186) that such terraces die out in certain directions, vary in level, and indicate local rather than widespread or universal movements. Although a raised beach may retain the same level for many miles, still between the horizontal strata which were upraised, and those which, lying outside of the elevated district, remained unchanged in level, there must be an intervening space, longer or shorter, where the strata slope down from the uplifted to the stationary ground.

206. To make this clearer, suppose by way of illustration that we place upon a table a number of sheets of cloth, to represent the different strata with which we are dealing. The cloths, like the strata, lie there horizontally. But if we push them up anywhere, they will be found to slope away from the elevated to the unmoved part. Put a flat tray, for instance, underneath them, so as to raise a considerable surface. Over the flat surface of the tray the cloths are flat, as they are in our raised beach, but from that upraised area they slope rapidly along the edges of the tray down to the undisturbed parts around. In like manner, a local elevation of land, even though it may raise up strata over a wide

district without disturbing their flatness, must yet give rise to an inclination of the strata round the outskirts of the uplifted region.

207. Wherever, therefore, strata are pushed up or let down more at one place than at another, without being actually broken across, they must be thrown into an inclined position. Now this unequal and irregular kind of movement has taken place many times in every quarter of the globe. Stratified rocks are seldom quite flat—usually they are inclined, sometimes gently, sometimes steeply, so that they have not only been upheaved out of the sea, but have been moved irregularly and unequally.

208. In the quarry described in Art. 104 the strata were horizontal. But in many quarries they may be seen to be inclined as in Fig 39, where the right-hand portion has been uplifted (or the left-hand parts have gone down) more than the others.

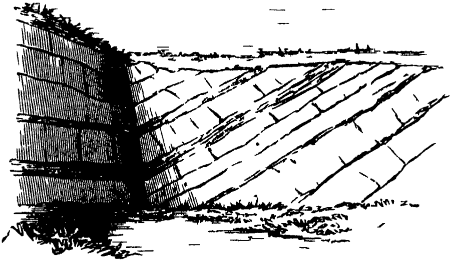

Fig 39 Inclined Strata

In some places, indeed, they have been so tilted up as to stand fairly on end (Fig. 40), like a row of books on a shelf. As they are made of sediment which gathered on a flat or gently sloping bottom, we see at once that they never could have been placed on end originally, but have been tilted into this position by underground changes.

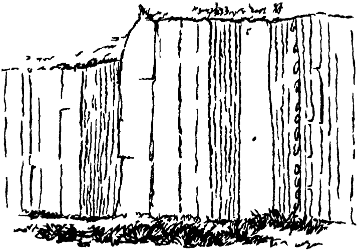

Fig. 40.—Vertical Strata

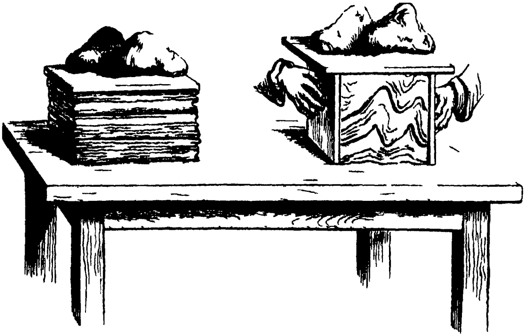

Fig. 41.—Cloths crumpled by lateral compression

209 But this is not all If when the cloths are lying flat on the table (Art 206) we squeeze them from either end, they will be thrown into crumplings (Fig 41) So, likewise, during the movements by which the strata of the earth's crust have been raised up, a great deal of rock crumpling has taken place In Fig 42, for instance sheets of hard limestone are shown to have been twisted and folded, as if they had been mere layers of cloth How enormous must have been the pressure to which such solid, resisting rocks were exposed before they were squeezed into these shapes!

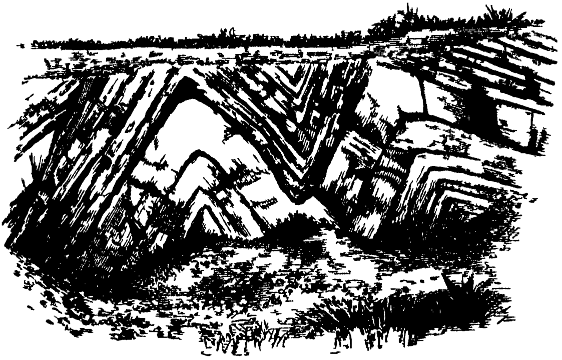

Fig 4 — View of contorted strata

210 One obvious difference between the cloths

and the strata is that the one are soft and pliable, and the others hard and rigid. But even the most unyielding rocks may be bent a little, and if this can be done, even with the comparatively feeble force and short time which man can employ, we may perceive how, under enormous pressure in the depths of the earth, prolonged during many centuries, rocks should have been crumpled up like mere pliable layers of cloth.

211. Still there must be a point beyond which rocks will rather break than bend. Cracks will then be formed, and the strata will be thrust up or pushed down. One of these cracks, or **faults,** as they are called, appears at *f*, in Fig. 37, where the coal-seams and the strata between them have been broken across—those on one side of the fracture being now found at a lower level than those on the other. Dislocations of this kind are of such frequent occurrence that the whole surface of the earth may be looked upon as a network of cracks. They greatly interfere with the working of coal-mines. In the section represented in Fig. 37, the galleries which are driven along the coal-seam, from the pit towards the left-hand, will need to be altered where the coal is cut off by the dislocation *f*, and shifted to a higher level on the farther side.

212. It has often happened that, into the cracks thus formed, masses of Igneous Rocks, while in a molten or soft condition, have been forced up from the interior, so as to cut across the other rocks. In

the section in Fig 43, for example, two such dislocations have occurred in a series of stratified rocks, so that three different groups, A, B, and C, have been displaced Into one of these cracks, on the left side of the diagram, a mass of Igneous Rock (I) has forced its way for some distance. But in the other, that to the right hand, a much larger body of melted rock has risen so as completely to separate the stratified rocks B and C, and not only so, but to break through the group B, ascending even to what is now the surface of the earth

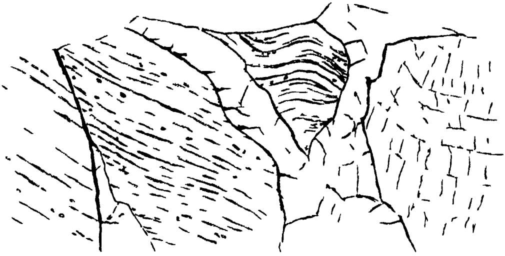

Fig 43 —Section of Igneous Rock forced up into Cracks or Fissures of the Earth's Crust

IV The Origin of Mountains

213 It is common to speak of the "eternal hills," as if they had existed from the very beginning of the world's history. And certainly few objects upon the surface of the globe convey to the mind such an impression of vast antiquity. As far back

as history or tradition can go, the mountains have remained without sensible change. And thus, because they have always appeared to man to be what they still are, he is apt to think of them as parts of the original architecture of the planet.

214. Yet from what has been learned in some of the foregoing Lessons, we may now be prepared to find that, old as the mountains undoubtedly are, they do not belong to the beginning of things. It is still possible to trace out their origin, and to get back to the records of earlier times, before they existed at all. The chronicles of this ancient history are contained in the rocks of which the mountains consist. We have already learnt how rocks can be made to tell their story. It is only a continuation of the same kind of reasoning, to inquire what they have to say regarding the birth of mountains.

215. First of all, then, when any chain of mountains is examined, it is found to be made of rocks belonging to one or more of the three great classes already described. In particular, the main mass of most mountain-chains consists of various kinds of stratified rocks—such as sandstones, conglomerates, limestones, and others. Now we have found (Art. 75) that these rocks have been laid down under water, most of them under the sea. They often contain the remains of shells, corals, sea-urchins, or other marine creatures, and these remains may be taken out of rocks even at the summits of mountains (Art. 145). No clearer proof could be required to

show that mountains are not so old as "the beginning of things," for those fossils prove that where mountains now stand the sea once rolled.

216. Again, mountains which consist of rocks formed originally under the sea must owe their existence to some force that could raise up the bed of the sea into high land. That force has been already (Arts. 169-172) alluded to. As a consequence of slow cooling, the outer crust of our planet, under the enormous strain of contraction, has been forced up into ridges in different places, with wide, sunk spaces between. The ridges form mountain-chains, while the deeper sunk spaces are filled with the waters of the ocean. On a map of the world we may trace out the principal **lines of elevation**, as they are called, over the globe. Perhaps the most remarkable of all the folds or puckerings into which the surface of the earth has been ridged up is the long band of mountains which runs down the whole of the continent of America. The various ridges of the Rocky Mountains, Central America, and the Cordilleras and Andes, are prolonged in one vast complicated line of elevation. Other minor foldings are seen on the same continent, as, for instance, the chain of the Alleghanies, in the eastern part of the United States. In Europe, a line of elevation stretches across the continent, and throws off spurs in its course. It is seen in the Pyrenees, then in the Alps, whence, after sending southwards the ridges of the Apennines, it is carried

eastward by the chain of the Carpathians, and then by the Caucasus to the Caspian Sea. The same band, however, reappears beyond the other side of that inland sea, and crosses the vast continent of Asia in two divergent branches; one of which turns south-eastward, to form the grand Himalaya, while the other trends eastward across the great Asiatic table-land to the shores of the Pacific Ocean. When these enormous mountain-chains are regarded as the results of the cooling and contraction of the mass of the globe, we feel how enormous must be the force which could crumple up solid rock into ridges many thousands of miles long and thousands of feet high.

217. But as the globe has been cooling and contracting from a very early period of its history, we may reasonably expect to find that mountains have been uplifted at various times, and, therefore, that they differ from each other in age. A little attention to their rocks is enough to show, not only that mountains are not all of the same age, but that even the same mountain has not been formed entirely at one time, but that one part has been raised up long before another.

218. Suppose, for example, that a series of ordinary sedimentary rocks, such as the sandstones, conglomerates, and shales, described in earlier Lessons, has been laid down upon the sea-bottom. These rocks would be formed one above another in flat beds (Fig. 44), until they had accumulated into a

mass perhaps many thousands of feet in thickness, which might remain undisturbed for a long time. Let us further suppose, however, that they happen to lie on one of those weaker parts of the crust which, when the accumulated effects of the long-continued contraction of the earth's mass begin to make themselves felt, are pushed outward or upward by the lateral thrust of the subsiding spaces on either side. Squeezed together by the pressure of these sinking areas, the formerly horizontal rocks will be crumpled up into folds (like our cloths in Fig. 41), and be made to rise above the level of the surrounding tracts (Fig. 45). A ridge or mountain-chain will thus arise upon the surface of the earth.

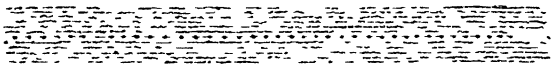

FIG 44.—Section of a series of Sedimentary Rocks originally deposited horizontally on the sea bottom

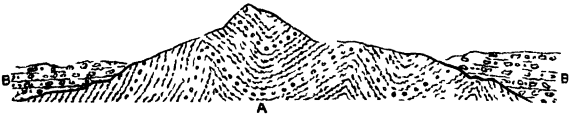

FIG. 45.—Section of a mountain formed of crumpled rocks, A, which have been contorted before the deposition of the flat rocks, B

219. Such a ridge or chain formed out of Sedimentary Rocks (A), once horizontal but now contorted, could not rise up into the atmosphere without becoming a prey to the various forces which are

ceaselessly at work in wearing down the surface of the globe (Physical Geography Primer, Arts. 133-147). What are called *the agents of denudation*, that is to say, air, rain, springs, rivers, frosts, and the waves of the sea, would attack the newly-formed mountain, and begin to waste its surface as soon as it raised its head above the level of the ocean. Deep furrows would thus in time be carved out of its sides. Hundreds or even thousands of feet of solid stone might be removed from its general surface, and all its decayed fragments would be washed down to the lower grounds and thence into the sea. There these materials would form new deposits, which would be laid down upon the edges of the older rocks, as the newer series B in Fig. 45 is seen to lie upon the older A.

220. Now such a section as this (Fig. 45) would enable us to fix, relatively at least, the date of the mountain. We can assert positively that (1) there was a time when the mountain did not exist, but when its place was occupied by a sea in which the sedimentary rocks A were deposited; (2) that the mountain was formed by the crumpling up of these rocks; (3) that after its uprise, its surface, during a prolonged series of ages, was enormously worn down by the agents of denudation; (4) that out of the detritus thus caused, a new series of sedimentary deposits (B) was formed which spread out horizontally above and around the upturned edges of the older rocks (A); and (5) that after the formation of the

younger strata, the whole mass was further uplifted, so as to raise these strata out of water into dry land.

221. But suppose that some other part of the chain should show such an arrangement of rocks as that represented in Fig. 46. Here, as before, we see that series A was upturned before series B could be laid down on it. But in the present case, series B has also been tilted up out of its original horizontal position, and was extensively worn down before a third series of sedimentary formations C was deposited on its upturned and denuded ends. Such a mountain would indicate three successive periods of upheaval, the first older than the time of B, the second older than the time of C, while the third came after the formation of C, for it raised that series of strata into land.

222. It is in this kind of way that the relative ages of mountain-chains are determined. In the two cases here represented by diagrams, it is obvious that the mountain of which the structure is given in Fig. 45 must be older than that in Fig. 46. In the one case, the uplift took place before the formation B was deposited, in the other it happened after that formation had been in its turn upraised. Wherever sedimentary rocks are found to stand on end or to be crumpled, we know that they have been disturbed, and wherever disturbed rocks have their broken edges covered by others, we see that the time of the uplift must have been intermediate between the formation of the two sets of rocks.

223. If now any means can be devised for recognising the same series of rocks in different countries: if, for example, we could be sure that the groups A and B of Figs. 45 and 46 occurred both in England and Germany, we should be able to compare the relative ages of the mountains of the two countries. If in the one country a mountain shows the structure represented in Fig. 46, and if in the other country a mountain formed of the same series of rocks is built up as represented in Fig. 45, we would infer that the former mountain was newer than, or, rather, had received a push upward after, the latter.

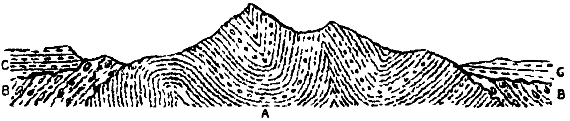

FIG. 46.—Section of a mountain in which the rocks A were upheaved before the series B, and the latter before the series C.

224. In the next Lesson, it will be shown how geologists identify the same series of rocks in different countries—viz. by Fossils. This kind of evidence enables us to decide which are the oldest and which the newest mountain-chains. It proves, for instance, that the giant Alps, towering so far above the plains of Europe, are less ancient than many a hill in Wales and Scotland.

225. But another singular and important fact about mountains is made plain by such sections as

those in Figs. 45 and 46. The series of rocks marked A is in each case the oldest part of the mountain. We might naturally suppose that the oldest ought to lie buried deep under the later portions; and yet, on examination, it is found that the most ancient parts are not always those which lie at the lowest level, but that, as in the two cases we have supposed, they may have been pushed up through the younger rocks, so as now actually to form the loftiest peaks and ridges. But if we explore the flanks of the mountain we find that the older rocks of the centre do really pass under the newer ones, as in the drawings series A passes under B.

226. The crumbling down of the surface of the earth is so constant and so widespread, that in process of time every mountain-chain undergoes great and manifold changes. Its summits and sides are wasted and lowered. Its crests are splintered into peak and pinnacle, as the rains and frosts of ages do their work upon them. Crag and cliff are carved out of its sides; ravine and gorge, wider glen and still wider valley, are excavated in its rocks by the never-ending flow of rill and river. Hence, though the original line of elevation remains, the upheaved tract is cut into innumerable ridges and valleys as the ceaseless waste goes on.

227. So enormous have been the effects of this slow but continuous destruction over the surface of the earth, that great table-lands or broad masses of

high land have been cut down into mere ridges and detached hills. In Fig. 47, representing a scene on the table-land of Spain, we may, as it were, watch how the excavation advances We may observe how the streams, as they descend and become larger in size, dig wider and deeper trenches out of the rocks, how their ravines broaden into valleys, how the high ground between them is trenched into irregular ridges, and how these ridges, still further cut into separate hills or mounds, lose height as the rains and frosts attack their summits and sides. In every quarter of the globe illustrations of these changes may be found. In Britain, for example,

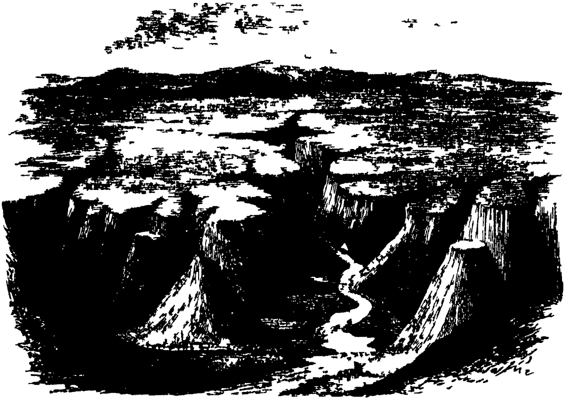

FIG 47 —View of a table land cut into ridges and valleys by the flow of its rivers

the mountains are only fragments, like those in the drawing, which have been left after the excavation of the valleys that surround them. The picturesque sandstone columns and ravines of Saxony, the great Ghauts of India, the Table Mountain and the innumerable "kops" and "kopjes" of Southern Africa, the cañons and buttes of Western America, are likewise conspicuous instances of the same kind of origin.

228. The forces which have carved out valleys, leaving mountain-ridges standing up between them, are still busy at their work. Every year adds to the waste. And thus, although, when we gaze at a mountain-chain, we know that first of all it was heaved up by movements from below, we nevertheless learn to recognise that all the familiar forms which it now assumes have, since that early time of upheaval, been carved upon it by the very same agents—rains, frosts, springs, glaciers, and the rest —which are busy sculpturing its surface still.

V. How the Rocks of the Crust tell the History of the Earth.

229. When a historian betakes himself to write the history of his country, his first care is to make himself acquainted with all the scattered documents likely to throw light upon the transactions which he will have to describe. He ransacks the papers in the public archives and libraries, gleans what he can from printed books, studies ancient monu-

ments, and even, it may be, travels into foreign countries in search of contemporary writings which may explain what is dark or uncertain at home. Only after prolonged labour of this kind is he able to gather up the sum of all he has learnt and to weave it into a continuous narrative. In the course of his researches he will no doubt find certain periods much better illustrated by contemporary documents than others, while of some he may possibly be hardly able to collect any satisfactory information, either because there never existed any written records of them, or because in the course of time the papers which would have supplied him with the facts are lost or destroyed. Hence his history is not all equally full and reliable. There may even be gaps in it, which no amount of industry in his search for information will enable him to fill up.

230. Now what is thus true of the historian of any country is true also of the geologist. As already pointed out (Art. 39), and as must now be clear from all that has been brought forward in the foregoing Lessons, the earth has a history, as well as the people who dwell upon its surface. A geologist may be called a historian of the earth. His great aim is to collect all the evidence which remains of the changes that have happened upon the earth's surface, and to arrange it in the order in which the events have occurred, so as to show the grand march of geological history down to the present time.

231. What papers and inscriptions, monuments, coins and books, are to the historian, the rocks of the earth's crust are to the geologist. They contain nearly all the evidence at his disposal. What he can gather from them at one place must be compared with what he collects from them at another. He must journey far and wide in search of facts which are not to be found at his own door. Gaps will certainly occur, which even the skill and industry of many years may never completely bridge over; for the rocks, as we have already seen, are subject to revolutions quite as destructive in their way as those which have swept away the archives of cities and nations. The geologist, therefore, can only at the best produce an imperfect chronicle. But it is one which has a profound interest for all of us, seeing that it is the story of our own globe—of its continents and oceans, its mountains and valleys, its rivers and lakes, of the tribes of plants and animals which people its surface, and of the advent and progress of man himself.

232. Regarding the earliest stages of the earth's history no direct evidence is now to be obtained from the rocks. But from the researches that have been carried on regarding the constitution of the sun and stars, it has been inferred that the sun and the earth, together with all the other heavenly bodies, embraced in what is called the Solar System, formed one vast **nebula** or cloudy mass of matter, and that the earth and the other planets which revolve round the sun

have, one after another, been detached from the nebula, of which the sun is now the remaining central mass. When the earth quitted its parent sun and became an independent planet, it must have been a fiercely hot mass, as the sun is still. Not until long after that period could any such rocks as we now see have been formed. So that although the rocks carry us a vast way back into the past, they cannot bring us to the beginning of the earth's history as a separate planet. The changes of that early time must be mainly inferred from astronomical evidence, combined with a study of the structure of the earth itself.

233. The foregoing pages have been written to show how the various kinds of rocks may each be made to give up its little bit of earth-history. We succeeded in discovering, for example, from the rocks of a single quarry, the site of an old sea-floor with some of the remains of the sea-creatures which lived upon it (Arts. 113-116). Again, we found how a peat-moss might enable us to trace out the limits of a long-vanished lake on which our forefathers launched their oak canoes (Arts. 129-137); and how the rocks of a coal-pit could furnish forth a record of forest after forest which had each flourished green and fair at the surface, but which had sunk down one after the other, and were now buried deep within the earth. (Arts. 198-202.)

234. In these and all such illustrations, while each series of rocks tells its own story, that story

is only a part of the general history of the earth. The more carefully we can gather the details for each separate narrative, the fuller will be that general chronicle of the earth's history which it is the object of geology to compile.

235. According to the law of superposition (Art. 107) the undermost stratified rocks are the oldest. We can reach but a little way down into the earth. The deepest mines or borings descend only a few thousand feet below the surface. If, therefore, these rocks still lay flat as they were deposited, we should be able to make ourselves acquainted only with those near the surface. But in consequence of the way in which the rocks have been bent, broken, and upheaved (Arts. 204-212, 213-225), we not only see the topmost parts of the series, but even some of the oldest masses. Instead of lying flat, the rocks are very commonly found to slope into the earth more or less steeply, and we can walk over their upturned edges, like the backs of so many rows of books. (See Figs. 38 and 39.) So far, therefore, from the bottom rocks being still buried under the thousands of feet of solid rock beneath which they once lay, they are often found rising into the summits of lofty mountain-ranges (Art. 225). The geologist, consequently, does not need to sink deep bores and pits to find out the order of the rocks under his feet. By making careful sections from what can be observed at the surface (as in Figs. 45 and 46), he can usually determine that order with certainty, and when he

has done so, he knows which are the oldest parts of his chronicle, and which are the newest.

236. The crust of the earth, so far at least as we can examine it, is chiefly made up of Sedimentary and Organically-derived Rocks. In these rocks, therefore, must the chief sources of evidence for the history of the earth be sought. If we could pile them up, one above another, in the order of their formation, they would form a mass probably more than a dozen miles thick. This, then, is the library out of which geological history must be compiled.

237. Besides the order of superposition, the geologist has another clue to the relative age of rocks. By comparing the different series of rocks with each other, he has discovered that the fossil plant and animal remains of one series differ from those of another. For example, to turn again to Fig. 46, it is ascertained that if fossils occur in the set of rocks marked A, they will be found to differ from those in the series B, and these again from those in C. If, starting from the plants and animals of to-day, we go back into older and yet older rocks, we learn that the fossil plants and animals become, on the whole, more and more unlike those which are still living. Each great division of rocks is found to have its own characteristic fossils. So that, over and above the test by Order of Superposition, we can discriminate between these divisions by means of Fossils.

238. By these methods of classification, the vast

complex mass of Stratified Rocks may be grouped into a few great divisions, these into sub-divisions, these again into minor compartments, and these into still smaller zones or bands, so that when a bed of rock is found it can be referred to its own particular part of the whole vast series. This method of arrangement is necessary for the sake of clearness, very much in the same way that a work on history requires to be divided into volumes, these into separate books, these again into chapters, and these into pages and lines.

239. Making use of every kind of evidence which the rocks afford, the geologist endeavours to weave together his narrative of the history of the earth. He shows how land and sea have often changed places, how, time after time, volcanoes have broken out in all quarters of the globe, how continents have been gradually built up, how mountain-chains have been successively formed, how valleys, ravines, and lakes, have been excavated, how climates have slowly changed from tropic heat to arctic cold. Amid all these revolutions of the solid earth itself, he finds that there have been, at the same time, vast changes in the plants and animals which have peopled its surface. He can trace how life, beginning in the remotest past with the simplest organisms, has advanced through long ages, in more and more highly organised forms (Art. 117), up to the present time. He can mark how group after group of shells, or fishes, or reptiles, has come into existence, and,

after living for protracted periods, has died out to make way for newer tribes, until towards the close of the history Man has appeared upon the scene.

240. Geological history brings before us, in this way, many facts well calculated to impress our minds with the great antiquity of our planet, and with the marvellous chain of changes by which the present order of things has been brought about. We learn from it that mountains and valleys have not come suddenly into existence, such as we now see them, but have been formed gradually, by a long series of processes similar to those which are even now slowly doing the same work. We discover that every part of the land under our feet can yield us up its story, if we only know how to question it. And, strangest of all, we find that the races of plants and animals which now tenant land and sea, are not the first or original races, but that they were preceded by others, and these again by others still more remote. We see that there has been upon the earth a history of living things, as well as of dead matter. At the beginning of that wonderful history we detect traces merely of lowly forms, like the foraminifera of the Atlantic ooze. At the end we are brought face to face with Man—thinking, working, restless Man, battling steadily with the powers of Nature, and overcoming them one by one, by learning how to obey the laws which direct them.

CONCLUSION.

241. The writer of this little book began to learn his geological lessons when he was still a schoolboy; but it was not from books that he learnt them. The mere accident of finding some fossils during a half-holiday excursion turned his thoughts towards such subjects, which soon became the chief employment of his leisure. He can look back upon these country rambles in search of fossils and rocks, not only as among the happiest hours of his life, but as having been of the utmost importance to him ever since. It is from his own deep experience, therefore, that he would in conclusion address a few words directly to his young readers who have the race of life before them, and whose progress in that race may be happy or unfortunate according to the habits of thought with which they start.

242. The main object of these lessons has been, not so much to teach dry facts, as to show how you may use your eyes in observing nature, and your judgment in dealing with your observations. Geology is so vast a subject that only a mere sketch of some parts of it could be given here, and those parts have been chosen which seemed to offer the greatest opportunity for enabling you to test the written lessons by a direct appeal to what may be seen every day around you.

243. It is not the design of these chapters to

enter further into the history of the Earth. They have led you to the threshold whence you can see the kind of interest in store beyond. You have now learnt something of the general principles upon which the history is based. Looked at in the light of geological teaching, the very stones of the street and the pebbles of the shore have each a meaning. If you have caught the spirit which these pages have tried to raise, you will no longer be content to gather minerals and rocks, as schoolboys usually do, merely because they are pretty objects to look at. Apart from their beauty you will seek to learn what they are, and what story they have to tell about the history of the land.

244. A landscape will lose none of its beauty in your eyes, though you inquire how the rocks of its hills were formed, how ridge and valley came into existence, why a crag should rise in one part and a wide plain stretch away for miles in another. When you stand by the brink of a foaming river, there will be no lessening of your pleasure in its rush and roar, if you think of the river as one of nature's most powerful engines, busy day and night in digging out its channel in the rocks, and carrying the waste of the mountains down to the plains and to the depths of the ocean. The shores of the sea will wear a new charm, when you trace, along their cliffs and caves, the progress of decay, and on their beaches of sand and shingle, the counterpart of those sedimentary deposits out of which whole mountains are built up.

245. Every quarry, ravine, and beach, where the naked rock comes to view, offers an attraction. Perchance you may there find the remains of some lost forms of plants which once bloomed green and luxuriant upon the land, or of long extinct tribes of animals which once tenanted the sea. These fossils will become, in your hands, not mere things to wonder at. You will try to learn, from friend or book, what they resemble most in the present living world. And you will not rest contented until you have done all that you can to understand whether and in what way they reveal the former condition of the district in which you find them.

246. Geology will thus be no mere task to be conned from books, but a delightful companion in every walk and ramble. You may not become geologists, but you will never regret the time you have spent in trying to master the principles on which geological science is based, and to trace out, under their guidance, the marvellous History of the Earth.

QUESTIONS.

INTRODUCTION.

1. Mention some of the most familiar kinds of Stone and the Uses to which they are applied.

2. What are Brick and Mortar made of?

3. How is Iron obtained?

4. What is meant by "Mineral Substances"?

5. Whence are Limestone, Slate, Marble, and Coal obtained?

6. Under what kind of covering do the Rocks of a country for the most part lie?

7. What is the general character of the surface of Britain along a line drawn from Liverpool to Harwich?

8. What is the general character of the surface of Britain along a line drawn from Skye to Montrose?

9. Explain why this difference of character should exist in two parts of the same country.

STONES OR ROCKS—THEIR VARIOUS KINDS, p. 8.

1. What use is made of Rocks in Geology?

2. What is meant by a Principle of Classification?

3. Show why mere colour, or hardness and softness, would not be sufficient as a Principle of Classification of Stones.

4. Describe the characters of a piece of Sandstone.

5. From these characters how would you define a Sandstone?

6. Describe in the same way the characters of a piece of Granite.

7. Give a definition of Granite from these characters.

8. Describe the characters of a piece of Chalk, and explain how the examination of the specimen should be carried on.

9. Give a short definition of Chalk from these characters.

WHAT STONES HAVE TO TELL US, p. 18.

1. What is the use of Classification in Science?

2. In what sense is the word "Rock" used in Geology? Give examples of different kinds of Rocks.

3. Are the various kinds of Rock scattered at random over the surface of a country? Illustrate this answer by reference to the stones which underlie the soil of Britain.

4. What kind of history is made known to us by Rocks? Give illustrations from the Rocks of Britain.

5. What is the subject of the Science of Geology?

SEDIMENTARY ROCKS.

I. What Sediment is, p. 24.

1. Into what groups may the different kinds of Rocks be divided?

2. What is Sediment? Show how the answer may be practically illustrated.

3. What are Sedimentary Rocks?

4. Describe a piece of Conglomerate, and show out of what materials it has been formed.

5. Of what materials does Sandstone consist?

6. What is the composition of Shale?

7. What two questions about their origin do Sedimentary Rocks suggest to us?

II. How Gravel, Sand, and Mud are made, p. 29.

1. What question is it well to put to ourselves when we try to find out the history of any kind of Rock?

2. What is the difference between Gravel and Sand, and how may this be shown?

3. Describe the origin of the Rubbish which covers the slopes of Mountains and high Hills.

4. The component fragments of this rubbish are usually sharp-edged, but become more and more rounded as they descend the neighbouring streams. Explain this change.

5. What effect has the Transport of the stones and sand upon the rocky beds of the streams?

6. Why does fine Mud travel farther down a stream than coarse Gravel?

7. In what form is the debris of the Mountains strewn over the Plains?

8. On a rocky sea-coast what is the difference between the surface of the rocks of the Cliffs and those of the Beach? Explain the cause of this difference.

9. What becomes of the Fragments which fall from the face of a Sea-cliff?

10. What is the origin of Gravel and Sand?

11. Explain the origin of Water-worn surfaces of stone.

III. How Gravel, Sand, and Mud become Sedimentary Rocks, p. 39.

1. What mainly determines the Transporting Power of a Stream?

2. What is the relation between the Rate of Motion of a Stream and the Deposit of Sediment at the bottom of the water?

3. In what Order are the different sizes of Sediment deposited?

4. What would you infer from beds of Gravel, of Sand, and of Mud, as to the Rate of Movement of the water in which each of these deposits is laid down?

5. How would you apply your knowledge of the origin of Gravel and Mud to the history of rocks like Conglomerate and Shale?

6. Where and in what way are Sedimentary materials arranged by rain upon a roadway?

7. How is the Sediment disposed of by the Rhone at the Lake of Geneva? How can this be proved?

8. What becomes of the Sand and Mud brought down by a river to the sea?

9. Define the terms *Stratification* and *Stratified Rocks*.

10. Why have Sedimentary Rocks usually become harder

than they originally were? Explain the terms *Pressure* and *Infiltration* with reference to the history of those rocks.

11. Define a Sedimentary Rock.

IV. How the Remains of Plants and Animals come to be found in Sedimentary Rocks, p. 53.

1. What are Organic Remains or Fossils?
2. Give some illustrations of the Burial of the remains of Land-plants in modern Sedimentary deposits.
3. Explain how Plants have been often imbedded in Sandstone and Shale.
4. Explain the origin of the Remains of Marine Animals in many Shales and Limestones.

V. A Quarry and its Lessons, p. 59.

1. What is usually the most obvious feature in a Quarry among Stratified Rocks?
2. Which are the Oldest of the different Beds in the quarry, and why?
3. What is meant by the term *Order of Superposition*?
4. Why is it important to determine the Order of Superposition?
5. What are Ripple-marks in rocks? What light do they cast on the history of the rocks among which they occur?
6. What are Rain-prints in rocks? What evidence do they furnish as to the conditions under which the rocks were formed?
7. How could you determine from the evidence of Fossils whether a rock had been formed in Fresh water or in the Sea?
8. Mention any facts which show the former spread of the Sea over what is now Land.

ORGANICALLY-DERIVED ROCKS, OR ROCKS FORMED OF THE REMAINS OF PLANTS AND ANIMALS.

I. Rocks formed of the Remains of Plants. p. 66.

1. Why are *Organic Remains* so called?
2. Briefly describe the characters of a piece of Coal.

3. Describe the way in which Coal occurs among other rocks.

4. What is the nature of the Under-clay of a Coal-seam?

5. How may the minute Structure of Coal be examined?

6. What has been the origin of Coal?

7. Describe a Peat-moss or Bog.

8. What is Peat? and to what use is it put?

9. Describe the successive Strata often to be seen at a Peat-moss, and show how they reveal the stages in its History.

II. Rocks formed of the Remains of Animals, p. 78.

1. What is the origin of the white Marl commonly found on the bottom of fresh-water lakes? What objects are occasionally found in it?

2. What is the Ooze of the Atlantic bed?

3. In what respects does Chalk resemble the Atlantic Ooze?

4. Under what condition is Limestone now forming on the Sea-bottom?

5. What is the origin of ancient Limestone containing the remains of corals and shells?

6. Give from various parts of the world examples of large districts and whole mountains made up of Limestone formed of Animal Remains.

7. Give a summary of the geological changes represented by Sedimentary and Organically-derived Rocks.

IGNEOUS ROCKS.

I. What Igneous Rocks are, p. 86.

1. In what sense has the word "Igneous" been used in Geology, and what is meant by Igneous Rocks?

2. Compared with Stratified Rocks what is the relative abundance of the Igneous series?

3. Describe generally the distribution of Igneous Rocks in Britain, on the Continent of Europe and in North America.

4. Into what groups may the materials ejected by Volcanoes be divided?

5. How are the rocks of these two groups broadly to be dis-

tinguished from each other, and what names may consequently be given to them?

6. Give a brief summary of the characters of Lava.

7. In what form does Lava issue from a Volcano? Describe a moving Lava-stream.

8. What is the origin of the little round holes so abundant in many solidified Lavas?

9. What is the origin of the columnar arrangement of some Lavas?

10. Give examples of the occurrence of Lava-rocks in different parts of the world.

11. How may the former existence of active Volcanoes be proved in districts where volcanic action has for many ages entirely ceased? Illustrate the answer from the British Islands, from the European Continent and from North America.

12. How does Granite occur?

13. What are the characters of a piece of Volcanic Tuff?

14. How has Volcanic Tuff been formed? Give some examples of its occurrence.

II. Where Igneous Rocks come from, p. 98.

1. What evidence is furnished by deep Bores and Mines as to the Temperature of the Interior of the Earth?

2. What is the testimony of Hot Springs on this subject?

3. What lesson do Volcanoes teach as to the condition of the Earth's Interior?

4. Briefly describe the distribution of Active Volcanoes over the surface of the globe.

5. What are Dormant and Extinct Volcanoes?

6. How are Earthquakes related to this subject?

7. On what grounds may it be inferred that the Earth is less in size than it once was?

8. Whence has the present high temperature of the Earth's Interior probably been derived? Show how the cooling of a Lava-stream helps to make this clearer.

9. What effect has the contraction of the Earth had upon its surface?

THE CRUST OF THE EARTH.

I. Proofs that parts of the Crust have been pushed up, p. 106.

1. What is meant by the Earth's Crust?

2. Of what materials does the Earth's Crust consist?

3. By what kind of evidence could you show that the rocks of the Earth's Crust are not now in their original position?

4. Describe a Raised Beach.

5. Mention some causes that seriously affect the Sea-level.

6. State the evidence from which it is inferred that Raised Beaches indicate unequal uplift of the Land rather than a fluctuation of the level of the Sea.

7. Briefly describe the Raised Beaches of Britain and Norway.

8. In a series of successive Raised Beaches, which are oldest, and why?

9. What facts have been observed in Sweden regarding recent Movements of the Earth's Crust?

10. How could you show that the greater part of the dry Land has been raised out of the sea, and that the Upheaval has been very unequal?

II. Proofs that parts of the Crust have sunk down, p. 118.

1. Describe a Submerged Forest.

2. What conclusion is to be drawn from Submerged Forests as to Movements of the Earth's Crust?

3. Why is it more difficult to find Proofs of Submergence than of Upheaval?

4. What facts about Submergence have been observed in Greenland?

5. How does a series of Coal-seams prove former Submergence of the Land?

6. Mention the two conclusions as to the movements of the

Earth's Crust which must be drawn from the evidence brought before us in these Lessons.

III. Proofs that the Rocks of the Earth's Crust have been tilted, crumpled, and broken, p. 124.

1. Besides Upheaval and Depression, mention some further changes which have been undergone by the rocks of the Earth's Crust.

2. Why are rocks often found in highly inclined positions, and how could you prove that these were not their original positions?

3. Are solid beds of rock ever folded and crumpled?

4. What are Faults?

5. What use of Faults has often been made by Igneous Rocks?

IV. The Origin of Mountains, p. 130.

1. Of what materials are Mountain-chains built up?

2. By what proofs can it be shown that many Mountains are not original parts of the earth's surface?

3. What are Lines of Elevation, and how have they been formed on the face of the globe?

4. Describe some examples of such Lines.

5. Briefly state the nature of the evidence by which it can be shown that Mountain-chains differ from each other in age, and that the same mountain may have been upheaved at successive intervals.

6. Why are the lowest and oldest rocks often found to form the higher central ridges of a Mountain-chain?

7. What effects are produced upon the external forms of Mountains, Table-lands, and Plains respectively during the general waste of the surface of the land?

8. What has been the origin of the mountains and valleys of Britain?

9. Give some further examples of the results of the wasting of the surface of the land.

V. How the Rocks of the Crust tell the History of the Earth, p. 140.

1. What is Geological History, and from what kind of evidence is it compiled?

2. Why is Geological History necessarily imperfect?

3. What has probably been the origin and early condition of the Earth?

4. How does the geologist learn which are the oldest and which the newest parts of his Chronicle?

5. How thick is the mass of Sedimentary and Organically formed Rocks out of which Geological History is compiled?

6. How do Fossils aid the geologist in the study of the history of the Earth?

7. Give some account of what is meant by Geological History.

LIST OF SPECIMENS to illustrate the GEOLOGY PRIMER.

Sedimentary Rocks	*See Primer, page* 21
1. Conglomerate	27
2. Sandstone	13
3. Shale	28
4. Shale containing Plant-remains (portion of a Fossil Fern)	53
5. Shale containing Animal-remains	57
Organically-derived Rocks	66
I. FORMED OF PLANT-REMAINS	66
6. Peat	73
7. Coal, showing stratified structure	67
II. FORMED OF ANIMAL-REMAINS	78
8. Fresh-water Shell-marl	78
9. Ooze from bottom of Atlantic prepared for the microscope	80

PAGE

10. Chalk with Shell in it 82
11. Grains of Chalk prepared for microscope . . . 17
12. Limestone containing Encrinites, etc. . . . 83

Fossils 53

I. PLANTS.

13. Stigmaria, or Sigillaria
14. Lepidodendron . . . } Plants out of which coal has been partly formed. 72

See also Nos. 4, 6, *and* 7.

II. ANIMALS.

15. Cup Coral
16. Piece of Encrinite stem . .
17. A Brachiopod (marine shell) . } Animals of which the remains sometimes form thick masses of limestone. 64

See also Nos. 5, 8, 9, 10, 11, *and* 12.

Igneous Rocks 86
18. Granite 15
19. Mica . .
20. Quartz Crystal } Substances found in Granite . 15
21. Lava showing crystals and steam holes . . . 89
22. Volcanic Tuff 97

A small box containing the collection, price 10s. 6d., may be obtained from F. H. BUTLER, 158 Brompton Road, London, S.W. ; J. R. GREGORY & CO., 1 Kelso Place, Kensington, London, W. ; or from MESSRS. MACMILLAN.

Printed by R. & R. CLARK, LIMITED, *Edinburgh*